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## THE GEOLOGY OF CEYLON[1]

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### Archean

### Petrography

#### The Quartzose Biotite Gneisses of the Ordinary Type

These gneisses underlie a very large part of the Island and display a general uniformity of type.

They are composed of quartz and orthoclase as the chief constituents, associated with which is usually a subordinate amount of plagioclase. The quartz is abundant. The dark constituent is biotite, sometimes associated with a deep green or brownish green hornblende. A few grains of pink garnet are often present, with apatite, zircon, and iron ore as frequent accessory constituents and present only in very small amount. The zircon appears in thin sections of the rock in the form of small rounded individuals or in minute prisms with rounded edges. The orthoclase in many places shows a fine perthitic structure due to a microscopic intergrowth of albite. This is seen in a striking manner in the biotite gneiss about Mehintale, the celebrated Buddhist shrine in northern Ceylon. Occasionally grains of micropegmatite are seen in the thin sections. The gneisses are pale reddish to light grey in color. They are usually rather fine in grain, well foliated and often show alternate bands differing somewhat in color or in size of grain.

These rocks with their minor variations and changes in size of grain and relative proportion of the constituent minerals bear a striking resemblance to the ordinary orthoclase gneisses exposed over thousands of square miles in the Canadian Shield of North America.

#### The Charnockites and Associated Rocks of the Charnockite Series

*The Charnockites*

The distribution and geological relations of the charnockites are set forth on pages 447-453; here a description will be given of the petrographical character and chemical composition of these rocks as represented by eight of the largest and most typical occurrences.

[1] *For the first part of this paper see Can. J. Research, November, 1929.*

These are as follows:

1. The great intrusion at Haputale—
   a. At its upper surface.
   b. Within the intrusion 320 ft. from its upper surface.
2. The occurrence on the Bulutota Pass.
3. The exposures at Hatton—in central Ceylon.
4. The exposures at Nuwara Eliya—in central Ceylon.
5. The quarry of the Public Works Department at Galle, on the south coast of Ceylon.
6. The quarry about two miles from Galle, on the south coast of Ceylon.
7. Dondra Head, on the south coast of Ceylon.
8. The great development near the west coast of the Island to the northeast of the city of Colombo.

The great intrusion of Charnockite at Haputale

Haputale is a station on the Ceylon Railway strikingly situated at the edge of a depression in the third or highest plateau. Going south from it the road winds down the face of a precipitous descent to the lowest or coastal plain. This precipice cuts vertically through a great intrusion of charnockite having a thickness of 2,000 ft. The charnockite of this intrusion was examined at two points—one being at the upper surface of the mass (a) and the second a point within the intrusion 320 ft. from its upper surface (b).

a. Charnockite at the upper surface of the Intrusion

The rock is very fine in grain, very dark greenish-grey in color with a vitreous or almost greasy lustre. It closely resembles in appearance the charnockite from the original locality at St. Thomas' Mount near Madras.

Under the microscope it is seen to be composed chiefly of quartz and an alkali feldspar, with less diopside and garnet and still less plagioclase, ilmenite and apatite.

The texture is granitic, but the rock shows a distinct tendency to a parallel arrangement of the constituents, which tendency is also seen, although perhaps less distinctly in the charnockite of the original locality at St. Thomas' Mount.

The alkali feldspar does not show the microcline structure which is seen in the original charnockite but sometimes displays a micro-perthitic structure. As shown in the norm, both orthoclase and albite are present, the former preponderating. Both diopside and hypersthene are present. They resemble one another so closely that it is impossible to determine in the case of every grain to which species it belongs. Neither mineral shows schillerization products, both are fresh and of a pale green color. When the sections are suitably cut, however, the diopside is found to be positive in sign, while the hypersthene is negative. The diopside is not pleochroic and the hypersthene shows in really thin sections a barely perceptible pleochroism. The higher birefringence of the diopside and the highly inclined extinction also reveal the character of certain individuals. Probably 90% of the pyroxene is diopside.

The garnet is pinkish in color, perfectly isotropic and occurs in irregular shaped individuals, often holding inclusions of iron ore and appatite. No biotite or hornblende are present.

The results of a chemical analysis of this rock are given in Table I, B., while under A in the same table the analysis of the charnockite from the type locality at St. Thomas' Mount is given (67).

The norms of these two rocks are as given in Table III in columns I.A and I.B.

b. Charnockite from a point within the Intrusion 320 ft. from its upper surface

This was taken from a quarry about one mile from Haputale on the road going down toward Koslanda. It is opened up on the face of the precipice which cuts almost vertically through the whole thickness of the intrusion. It is 320 ft. from the upper surface of the latter and is identical in appearance with the rock exposed at Haputale, being fine in grain and very dark greenish grey in color. It holds occasional darker streaks, but is uniform in general character throughout.

Under the microscope it bears a very close resemblance, in composition and structure, to the rock at Haputale just described. It displays like it a tendency to parallel arrangement of the constituents. It differs from this rock, however, in that no garnet is present. The hypersthene preponderates largely over the diopside, while biotite and zircon occur as subordinate accessory constituents. Most of the quartz lies with the feldspar in the allotriomorphic mosaic of the rock, but the former mineral sometimes assumes more elongated forms running parallel to the foliation of the rock and which often show a slight undulatory extinction as though, being the last constituent to solidify, it had been drawn out into this form by the final movements before the actual solidification of the rock. No signs of cataclastic or protoclastic structure can be seen. As in the rock from Haputale, both diopside and hypersthene are present and what has been said concerning these two minerals in descriptions of that rock applies equally here. The pleochroism of the hypersthene is $\mathfrak{c}$=pale greenish. $\mathfrak{a}$ and $\mathfrak{b}$=pale pinkish. As noted above, the great bulk of the pyroxene present is rhombic pyroxene or hypersthene.

The results of a chemical analysis of the rock are given in Table I. C, and the norm in Table III (I.C.).

From the standpoint of chemical composition the most striking difference between this charnockite deep down within the intrusive, and the charnockite at the upper surface of the same great mass, is that this latter is lower in alkalies and higher in lime and oxide of iron, a difference which is indicated by the larger amount of anorthite and ilmenite and the smaller amount of alkali feldspar in its norm and by the garnet and the relatively larger amount of diopside present in its mode or actual mineral composition. It is also shown in the position of this rock in rang 3 instead of rang 2 in the Quantitative Classification. Both rocks have essentially the same specific gravity.

Charnockite on the Bulutota Pass

This rock resembles closely in appearance that from Haputale but it is rather coarser in grain. While in some parts of the occurrence it is practically massive, the charnockite usually shows a more or less well defined tendency to a parallel arrangement of the constituents. Under the microscope it is seen to be composed of an alkali feldspar and quartz with some hypersthene, hornblende, garnet and plagioclase, a smaller amount of iron ore and a few individuals of apatite and zircon. The alkali feldspar often shows microperthitic intergrowths. The hornblende and hypersthene vary somewhat in relative amount in different specimens, but in that analysed the two were present in about equal amount. The hornblende is highly pleochroic in green and brownish green tints. The zircon, which is seen in every thin section, occurs in well defined little crystals of stout prismatic form with square cross section, parallel extinction and the characteristic high index of refraction and high double refraction. The garnet is pinkish in color.

The results of an analysis of the rock are given in Table I. D, the norm in Table III (I.D).

Charnockite—Hatton—Ceylon

This charnockite is well exposed in a large quarry situated in the middle of the town of Hatton and opposite to the Railway Station. It is very dark grey in color, and like that on the Bulutota Pass it is rather coarser in grain than the charnockite from St. Thomas' Mount, or from Haputale. The mass is, as a whole, uniform in character but in places streaks somewhat lighter in color and a little coarser in grain are seen. A few little reddish garnets can occasionally be detected, but this mineral is usually absent. A little biotite is sometimes seen in the coarser grained schlieren. The rock, like the other charnockites here described, is perfectly fresh but in the quarry it is covered by a bright red and yellow lateritic clay, the product of its weathering.

Under the microscope the rock is seen to be composed of alkali feldspar, quartz and plagioclase with hypersthene and a little garnet and iron ore and still less biotite, hornblende, apatite and zircon. The plagioclase is andesine. The texture is allotriomorphic but there is a general tendency of the minerals to arrange themselves in one direction. There is, however, no evidence of any cataclastic or protoclastic structure, nor any signs of crushing.

The results of an analysis of this rock are given in Table I. E, its norm in Table III (I.E).

The only rock which has hitherto been analysed and has this position in the Quantitative Classification is a granophyre described by Horwood from Zonderwater in the Transvaal. Subrang 3 has had no name assigned to it as yet, but subrang 4 is bandose.

Charnockite—Nuwara Eliya

The rock is well exposed in a large quarry on the western outskirts of this town, at mile post 46.

It is dark greenish-grey in color and fine in grain, although the mineralogical character of some of the larger grains can be recognized under a lens. The rock in the quarry shows an indistinct foliation, which structure is visible also in the thin sections.

Under the microscope the rock is seen to have an allotriomorphic texture. It is composed very largely of quartz and feldspar. The analysis shows that 84.7 % of the rock is made up of these minerals. The dark color of the rock is due not to the prevalence of femic minerals but to a multitude of minute dark inclusions present in the salic minerals.

The feldspar is in part orthoclase and in part plagioclase. The former shows no microperthitic intergrowths but is occasionally intergrown with the quartz in the form of micropegmatite. The quartz is usually in the form of individuals very irregular in shape and rather larger than the other minerals of the rock. The femic minerals present are hypersthene, diopside, iron ore and apatite.

The two pyroxenes vary in relative abundance in different thin sections. The hypersthene is pale greenish in color and shows a distinct pleochroism in pale green and pale yellow tints. The diopside is of a rather deeper green color and is not pleochroic. It has an extinction of 38°. The iron ore is highly titaniferous. The apatite is present in large well-defined crystals and constitutes no less than 2% of the rock.

The chemical composition of the rock is shown in Table I. F, and the norm in Table III. (I.F).

From the norm, the mode or actual mineral composition of the rock may be derived and is approximately as follows:

| | |
|---|---|
| Quartz | 29.46 |
| Orthoclase | 20.02 |
| Soda Lime Feldspars | 33.58 |
| Hypersthene and Diopside | 7.52 |
| Titaniferous Iron Ore | 6.41 |
| Apatite | 2.02 |

Charnockite—Quarry of the Public Works Department—Galle

This large quarry is worked for road metal and affords an excellent exposure of the charnockite.

The rock is dark grey to nearly black in color and in the mass is nearly uniform in character. It is rather coarser grained than the St. Thomas' Mount charnockite. There is a faint parallelism in the arrangement of the constituent minerals, while in some of the schlieren one or other of the minerals of the rock are seen to be more abundant than usual. These variations however are not great and are often scarcely noticeable in the fresh rock but become distinctly visible when the rock is decomposed. Near the surface the rock weathers to a yellowish clay holding masses of the charnockite as boulders of decomposition.

Under the microscope the rock is seen to be composed of orthoclase and quartz with smaller amounts of a lime soda feldspar and hypersthene, with very small amounts of biotite and hornblende, iron ore, and still less apatite and zircon as accessory constituents.

The orthoclase often shows microperthitic or micropegmatitic intergrowths. The soda lime feldspar is andesine having the composition $Ab_3An_2$. The hypersthene has a very faint pleochroism in pale greenish-yellowish and reddish tints and frequently shows an approximation to its proper prismatic form. The hornblende is pleochroic in pale yellow to greenish-brown tints.

An analysis of one specimen of the rock gave the results set forth in Table I.G. That of another specimen, those given in Table I.H. The respective norms calculated from these analyses are given in Table III (I.G and I.H.).

Analysis H differs from analysis G chiefly in the higher percentage of lime, which in the norm shows in the increased amount of anorthite and in the presence of a small percentage of diopside.

In the specimen whose analysis is given under F, the plagioclase has the composition $Ab_1An_1$ while in that whose analysis appears under G the plagioclase is a more acid andesine having the composition $Ab_3\ An_2$.

Charnockite—about two miles from Galle

About two miles from the Fort at Galle a small quarry has been opened up for road metal, in which are exposed two interesting varieties of rock. The first of these is a charnockite, light greenish-grey in color and rather fine in grain, which in the hand specimen seems to be composed almost entirely of salic minerals. This rock is called by the Singhalese quarrymen "Glass Rock".

Under the microscope it is seen to be composed almost exclusively of quartz and alkali feldspars containing many minute dust-like inclusions. The only ferric mineral is now represented by a few forms filled with a pale greenish, more or less fibrous, serpentinous or chloritic alteration product. It was probably a pyroxene. The feldspars are orthoclase and albite in microperthitic intergrowths, with some few grains of micro-pegmatite. The quartz is abundant. There is also a little soda lime fedspar with titaniferous magnetite, zircon and pyrite, these latter as extremely subordinate accessory constituents.

An analysis of this rock is given in Table I. I. This as will be seen, is the most acid charnockite of the series analyzed, its content of $SiO_2$ being nearly as high as that of the original charnockite from the St. Thomas' Mount. Its norm is given in Table III (I. I).

The other variety of this rock present in this quarry occurs as occasional large "schlieren" in the charnockite just described. It is much darker in color and like the charnockite shows a faint parallelism in the arrangement of the constituent minerals. It is evidently a differentiation product of the charnockite magma.

Under the microscope it is seen to be composed of deep brown hornblende which makes up about one-half of the rock. This is optically negative, has an extinction of 24° and the following pleochroism and absorption:

Pleochroism — $\mathfrak{a}$ = deep brown; $\mathfrak{b}$ = reddish brown;
$\mathfrak{c}$ = pale brown.

Absorption — $\mathfrak{c} > \mathfrak{b} > \mathfrak{a}$.

With this is associated a pale greenish-grey non-pleochroic monoclinic pyroxene and a well twinned plagioclase. A very small amount of an untwinned alkali feldspar and a very few grains of pyrite are also present. The rock contains no quartz.

In this quarry therefore a very acid charnockite and a basic hornblende plagioclase rock are seen together as differentiation products of one magma.

Charnockite—Dondra Head

At a number of points on the south coast of Ceylon, to the east of Galle, charnockite exposures are seen, but a large body of the rock is met with at Dondra Head and forms this celebrated promontory which is the extreme southern point of Ceylon and indeed of the Continent of Asia in these longitudes. It is a rock of medium grain showing a distinct foliation, and very dark grey in color with occasional still darker streaks or schlieren. It is composed of quartz, alkali feldspar and soda lime feldspar, with smaller amounts of hypersthene, still less biotite and a little diopside, brown hornblende and magnetite. The quartz and feldspars contain many dark dust-like inclusions. The darker streaks referred to above are portions of the rock in which the iron magnesia constituents, and especially the biotite, are relatively more abundant.

Charnockite Area near West Coast of Ceylon, and Northeast of the City of Colombo

As a typical occurrence representing this area the charnockite which is excellently exposed in the large quarry at Tillawelmankada, known as the Hedidenikanda quarry, may be selected. This quarry is situated between mile posts 30 and 31 on the road between Colombo and Kegalla.

The rock is nearly massive. In the upper part of the quarry it is seen to pass into a yellow earth, the product of its secular decay. The line of contact between this residual soil and the fresh rock is very sharp.

This rock under the microscope is seen to be composed of quartz, alkali feldspar and pyroxene with some soda lime feldspar and very small amounts of iron ore, apatite and zircon as accessory constituents. In some sections a few minute grains of green hornblende are seen in association with the pyroxene.

Two pyroxenes are present, hypersthene and diopside. These as usual resemble one another very closely and present the characters already mentioned in the description of the charnockites given above. They differ in relative proportion in the several slides.

The orthoclase frequently encloses albite in microperthitic intergrowths and the quartz and orthoclase are occasionally associated in the form of micropegmatite.

The results of a chemical analysis of this rock are shown in Table I. J, the norm of the rock in Table III (I. J).

The mode or actual mineralogical composition of the rock closely resembles the norm. If the soda lime feldspar be taken as having the composition $Ab_3\ An_2$ the mode is as follows:

| | |
|---|---|
| Quartz | 23.70 |
| Alkali Feldspar | 33.78 |
| Soda Lime Feldspar | 27.80 |
| Diopside | 3.66 |
| Hypersthene | 8.85 |
| Titaniferous Magnetite | 1.45 |
| Apatite | .34 |

The charnockites from several of the other quarries on this road when examined microscopically were found to resemble closely the rock above described, the only noteworthy difference being that some of them hold in addition to the constituents already mentioned a certain amount, generally small, of biotite.

*Associated Rocks of the Charnockite Series*

The charnockites which have just been described form very large and important rock masses. Associated with them in various parts of the Charnockite Area are other bodies of rock usually dark in color, ranging from dark grey to black, and with a more or less distinct gneissic structure, which are also characterized by the presence of hypersthene or diopside, or of both pyroxenes together. These bear a resemblance to the charnockite. Others again hold hornblende with or without pyroxene. In some of these rocks the preponderating feldspar is orthoclase, in others it is a soda lime plagioclase. They contain more or less quartz and occur associated or interbanded with one another, or in many cases with the granulites or with the ordinary biotite gneisses of the Island.

These darker bands represent rocks varying in composition from charnockite through monzonitic and dioritic varieties, to gabbros and norites of different kinds. Among them are representatives of the Intermediate and Basic divisions of Holland's "Charnockite Series" in India.

Specimens from some thirty different occurrences of these rocks have been examined microscopically, but the rocks do not here merit individual description. The rocks from four of these occurrences, however, have been studied in more detail.

Rock intermediate between Charnockite and Quartz Norite, Pussellawa

The picturesque village of Pussellawa is situated in the central part of southern Ceylon on a steep hill slope with a deep valley lying to the southwest. The great rock cliffs here show immense exposures of a pale grey rock holding occasional darker bands giving it a bedded appearance, this apparent bedding being horizontal or nearly so. The rock at the first glance presents the appearance of an anorthosite, such as may be seen in many places in the Laurentian Area of Canada. Closer examination, however, shows that this rock is quite different in composition.

When examined with a lens or in thin sections under the microscope the rock is seen to have an indistinct foliation running parallel to the banding referred to above.

The pale grey rock from the village of Pussellawa when examined under the microscope was found to be composed of quartz, alkali feldspar and soda lime feldspar with a small amount of hypersthene and a very few grains of hornblende, biotite and iron ore. The hypersthene shows the usual faint pleochroism. The hornblende is deep brown and highly pleochroic.

The results of a chemical analysis of the rock are shown in Table II.B, and its norm in Table III (II.B).

This rock falls within a division of the Quantitative Classification which has no other representative.

The mode or actual mineral composition of the rock agrees closely with the norm. The alumina represented in the norm as corundum is probably present in biotite and hornblende.

The rock thus lies between a quartz norite and a charnockite.

Rock intermediate between Charnockite and Quartz norite, three miles southeast of Pussellawa

A second locality where this rock is excellently exposed is in the quarry about three miles southeast of Pussellawa, near mile post 26 on the Pussellawa road.

In hand specimen the rock closely resembles that just described. Under the microscope it shows a mosaic structure with, however, a distinct suggestion of foliation. Like the last, it is seen to be composed essentially of quartz and feldspar, both alkali and soda lime feldspars being present. The iron magnesia constituent originally present, although not in large amount, is now completely decomposed. Judging from the forms it was a pyroxene, but these forms are now filled with a pale green alteration product resembling chlorite in appearance but possessing a higher double refraction, together with some calcite. The only other minerals present are pyrite and ilmenite, both as very subordinate constituents.

An analysis of this rock is given in Table II. C. The norm of the rock is given under II.C in Table III.

The plagioclase which is present is an oligoclase having an extinction angle of 5° against the lines of polysynthetic twinning. This shows it to have a composition which lies between $Ab_6An_4$ and $Ab_3An_1$. Taking the composition to be $Ab_5An_1$, 7.86% of anorthite would be required to unite with the percentage of albite present. This would give 47.16% of oligoclase, leaving the rest of the lime, which in the norm appears in the diopside and wollastonite, for the alteration products of the small amount of pyroxene originally present. This rearrangement would give a rock composed of rather over 90% of quartz, orthoclase and acid oligoclase, which agrees with the composition of the rock as seen in the thin sections.

This rock, like the last, if the original pyroxene was rhombic, therefore lies between a charnockite and quartz norite in composition.

The dark bands, or schlieren, which occur at intervals in the rock and in many exposures give to it a bedded appearance, as already mentioned, are seen, when examined under the microscope, to be composed of plagioclase, pyroxene and hornblende in about equal amounts, with much less quartz and orthoclase, and with pyrite, magnetite and apatite as accessory constituents. The pyroxene is in part hypersthene and in part diopside, the former preponderating. The hornblende is deep greenish-brown in color and highly pleochroic as follows: $\mathfrak{a}$ = deep brownish green; $\mathfrak{b}$ = opaque; $\mathfrak{c}$ = very deep brown, almost opaque. It has an extinction angle of 27°. These represent more basic schlieren in the acid magma.

Rock intermediate between Charnockite and Hypersthene Gabbro Diorite, Nuwara Eliya

At Nuwara Eliya there are large exposures of a very dark grey gneissic rock having a general resemblance to charnockite in appearance. It is coarse enough in grain to enable some of the constituent minerals to be recognized with a lens.

Under the microscope the foliation can be distinctly seen and the rock is found to be composed of plagioclase, diopside, hypersthene and hornblende as essential constituents with small amounts of quartz, orthoclase, ilmenite, pyrite and apatite as accessory constituents.

The soda lime feldspar is the most abundant constituent. Its maximum extinction angle against the twin lines, as measured in the thin sections, is 16°, showing the feldspar to be an andesine having the composition of $Ab_{64}An_{36}$.

The diopside is pale green in color, is non-pleochroic, has a high extinction angle and is positive in sign. The hypersthene which is relatively less abundant shows a faint pleochroism in greenish, yellowish and pinkish tints, has a lower birefringence, and a parallel extinction and is optically negative.

The hornblende is brown with a strong pleochroism, $\mathfrak{a}$ = greenish-yellow; $\mathfrak{b}$ = brown; $\mathfrak{c}$ = greenish-brown. The absorption $\mathfrak{c} > \mathfrak{b} > \mathfrak{a}$. The extinction angle is 18°.

The results of a chemical analysis of this rock are given in Table II. D. From this the norm when calculated is found to be as given in Table III (II.D).

It is impossible to calculate the mode of this rock without a further knowledge of the actual chemical composition of certain of the constituent minerals.

It lies between a charnockite and hypersthene gabbro diorite in composition but nearer to the latter rock.

Garnetiferous Orthoclase Norite twelve miles from Colombo on the main road to Ratnapura

There is exposed by the road side at this locality a very dark greenish-grey rock which is practically massive and bears a strong resemblance to charnockite.

Under the microscope some sections show an indistinct tendency to a parallel arrangement of the constituent minerals, whereas in others the rock appears to be quite massive. It is composed of plagioclase, hypersthene and garnet, with less orthoclase and a little iron. The plagioclase, as mentioned below, is

andesine. The hypersthene presents the usual characters of this mineral in the charnockites already described. The garnet is pale pink in color and together with the hypersthene constitutes about one-third of the rock. An analysis of the rock is given in Table II.A, its norm in Table III (II.A).

If for the purpose of calculating the mode the diopside of the norm is taken, with 25 molecules of anorthite, 15 of magnetite and 20 of hypersthene, a combination is obtained which represents closely the composition of garnet and which gives 21.51% of that mineral. Deducting the amount of anorthite required for this garnet from the total shown in the norm, and combining the remainder with the albite present, 46.02% of andesine is obtained having a composition of $Ab_{63}$ $An_{37}$ which is almost exactly the composition of the plagioclase actually present, as shown by the extinction angle of 16° measured in the thin sections.

The mode or actual mineral composition of the rock is therefore as follows:

| | |
|---|---|
| Quartz | 0.60 |
| Orthoclase | 16.12 |
| Plagioclase | 46.02 |
| Hypersthene | 8.90 |
| Garnet | 21.51 |
| Titaniferous Iron Ore | 5.61 |
| Apatite | 1.68 |
| Pyrite | 0.25 |

This rock is therefore a garnetiferous orthoclase norite.

Garnetiferous Hypersthene Monzonite directly south of Kandy on the road between Gampola and Nawalapitiya, about mile post 16

A dark, distinctly banded gneissic rock resembling charnockite has been opened up in quarry at this point. The rock is exposed as a low anticlinal arch and is altered to a depth of 25 ft. from the surface into a red lateritic clay. In the lower portion of this clay the banding of the rock is still well preserved, but this disappears towards the surface where the clay forms the soil on which a thriving rubber plantation has been developed. The banded structure of the rock is due to the presence of alternate lighter and darker bands, although all of them may be said to be dark in color. All contain minute reddish garnets.

Under the microscope the rock is seen to be composed of orthoclase, plagioclase, diopside, hypersthene, hornblende and red garnet as the chief constituents, with quartz, iron ore and zircon as accessory minerals.

The monoclinic pyroxene and the hypersthene resemble one another closely both being pale green in color. The monoclinic pyroxene however is positive in character, has a large extinction angle and is not pleochroic. The hyper-

sthene, which like that in the other Ceylon rocks is free from schillerization products, is negative in character, has a parallel extinction and a distinct pleochroism as follows:

$\mathfrak{a}$ = reddish violet

$\mathfrak{b}$ = pale reddish yellow

$\mathfrak{c}$ = pale bluish green.

The hornblende is greenish-brown in color and highly pleochroic. The garnet occurs as occasional large individuals with inclusions of quartz and hornblende.

Garnetiferous Hypersthene Hornblende Gabbro. Road between Pelmadulla and Haldummulla, mile post 76

A rock, somewhat similar to that just described, is here opened up in another quarry which lies further to the southeast. The rock is dark in color and on the fresh fractured surface shows minute red garnets disseminated through it.

Under the microscope the rock is seen to be composed of plagioclase, diopside, hypersthene, hornblende with red garnet as essential constituents, but contains no orthoclase, quartz or iron ore.

The hornblende is deep greenish brown in color and has an extinction angle of 20°. It is strongly pleochroic as follows:

$\mathfrak{a}$ = pale brownish-yellow

$\mathfrak{b}$ = greenish-brown

$\mathfrak{c}$ = deep green

The absorption is $\mathfrak{c} > \mathfrak{b} > \mathfrak{a}$.

Rock between Charnockite and Norite. Quarry half a mile from the Rest House at Mahara about ten miles northeast of Colombo

Excellent exposures of this rock are seen here. It is a dark grey, nearly black gneissic rock which resembles charnockite in appearance and is cut by dykes and strings of red pegmatite.

Under the microscope it is seen to be composed chiefly of plagioclase and hypersthene with small amounts of orthoclase, quartz and biotite.

*General Character of the Ceylon Charnockites*

The Ceylon charnockites, as will be seen from an examination of analyses in Table I, B to J form a group of rocks which show a close agreement in composition. They are hypersthene granites, like the original charnockite, but as compared with it are somewhat more basic. As will be seen from the analyses given under A and K in Table I they contain on an average 9.35% less $SiO_2$ and are somewhat richer in MgO, CaO and FeO. The sum total of the alkalies in the two rocks is almost the same. One of the Ceylon rocks, Table I. I. approaches more nearly in composition to the original charnockite, but this is a comparatively small occurrence.

They also show a corresponding difference in specific gravity. That of the original charnockite being 2.67, while the average specific gravity of the Ceylon charnockites is 2.77.

The alkali feldspars—orthoclase and albite—are usually intergrown in the form of microperthite and minute grains of an intergrowth of these feldspars with quartz to form micropegmatite is not infrequently seen. The soda lime feldspar which is almost always present, though in much smaller amount, is almost always oligoclase.

The only femic minerals which are present in any considerable amount are hypersthene and diopside—the former preponderating largely in most cases. These minerals never show the schillerization products so frequently displayed by them in other allied rocks. They resemble one another very closely so that when present together it is often impossible to determine the character of every individual grain. They are both pale green in color but the hypersthene shows a more or less distinct pleochroism, in greenish, yellowish and pinkish tints, as already mentioned in describing the individual rocks while the diopside is practically non-pleochroic. The diopside in sections approximately parallel to the clinopinacoid shows of course the high angle of extinction which characterizes it, while showing parallel extinction in sections parallel to the orthopinacoid. This parallel extinction is also seen in almost all prismatic sections of the hypersthene. But in such sections this mineral sometimes shows an extinction which is not quite parallel to the apparent cleavage.

Washington (67) has noticed this also in the charnockites of the original locality and says concerning it, "This apparently anomalous oblique extinction is to be ascribed to the non-development of the usual prismatic cleavage, the coarse cleavage cracks seen being due to a parting or cleavage parallel to b (010)". He notes that in cleavage flakes the extinction is always parallel to the cleavage cracks. This is also true of the hypersthene in the Ceylon charnockites.

The hypersthene also possesses a lower birefringence than the diopside and is negative in sign, while the diopside is positive.

There has been much divergence of opinion with reference to the character of the pyroxenes in these Ceylon rocks and in the similar rocks of the Charnockite Series in India. Parkinson (52) states that he never found hypersthene in any of the rocks from Ceylon which he examined, but that they contain a monoclinic pyroxene with the pleochroism of hypersthene. Coomaraswamy (29) who examined certain rocks from the same localities as those mentioned by Parkinson, as well as from many other parts of the Island, states that he cannot find in these rocks or in any rocks in Ceylon an augite possessing the pleochroism of hypersthene. Lacroix (46) mentions a monoclinic pyroxene with a pleochroism similar to that of hypersthene from the pyroxene gneisses of Salem in southern India. Holland (40) referring to this statement states that he has examined hundreds of rocks from this district, similar to those described by Lacroix, and has never been able to discover a single instance of such a pleochroic monoclinic pyroxene, while one of the commonest rocks of these types

is one in which both pyroxenes occur together: one strikingly pleochroic and unmistably rhombic while the other is very feebly pleochroic in greens only, giving wide extinction angles. Washington (67) writing of certain rocks of the Charnockite Series in Southern India which he examined states that the hypersthene which they contain always shows a marked and characteristic pleochroism, but that the augite when present never shows more than a faint pleochroism. It is evident that when both minerals are present the greatest care is necessary to distinguish them and that in these cases especial attention should be paid to the birefringence and to the sign of the minerals.

The dark color which the charnockites possess is not due to the femic minerals which they contain for these are usually present in relatively small amount, but is caused by the presence of minute dust inclusions in the quartz and feldspars.

The charnockites in Ceylon almost invariably show a more or less distinct tendency to a parallel arrangement of the constituents, which is stated by Holland to be the case also in the original charnockite from near St. Thomas' Mount in Madras. This, however, is not accompanied by any cataclastic structure or other evidences of crushing but is due to movements of the magmas during the final stages of consolidation. This opinion has also been expressed by Holland (40) and by Coomaraswamy (24).

*Charnockites in other Regions*

The co-magmatic regions which are comparable with that of the charnockite areas in Ceylon are few in number, though widely scattered. That of southern India described by Holland (40) and to which frequent reference has already been made, is the nearest and probably the largest of them. Indeed this relatively small development in Ceylon should probably be considered a part of the much larger Indian area.

Other co-magmatic regions which resemble those of Ceylon are the Ekersand, Soggendal and Bergen districts of western and southwestern Norway (42), the eastern part of Ellesmere Land and Prudloe land across Smith's Sound (12), the Cortland Series near Peekskill, New York (56), the Ivory Coast in West Africa (45) and the granulite region of Saxony. A region in the Blue Ridge of Virginia (68) and certain occurrences (57) described by H. P. Cushing from Loon Lake, N.Y., and by C. H. Smith from Diana, N.Y., have certain relationships to the Ceylon charnockites.

A valuable discussion of the resemblance of these several regions to one another and especially to the charnockite region of India is to be found in Washington's paper to which reference has been made, and to which for further information the reader is referred.

TABLE I

ANALYSES OF CHARNOCKITES

| | A | B | C | D | E | F | G | H | I | J | K** |
|---|---|---|---|---|---|---|---|---|---|---|---|
| $SiO_2$ | 77.47 | 64.76 | 69.10 | 69.08 | 67.14 | 66.93 | 66.58 | 65.89 | 75.87 | 67.91 | 68.14 |
| $TiO_2$ | 0.26 | 3.44 | 1.23 | 2.77 | 3.81 | 2.59 | 2.92 | 0.55 | 0.05 | 0.61 | 1.99 |
| $Al_2O_3$ | 11.00 | 12.82 | 11.69 | 11.66 | 11.23 | 12.50 | 14.52 | 14.89 | 12.34 | 13.56 | 12.80 |
| $Fe_2O_3$ | 1.04 | 1.65 | 2.63 | 0.51 | 0.78 | 0.87 | 2.96 | 2.00 | 0.57 | 0.10 | 1.34 |
| FeO | 2.02 | 5.71 | 3.38 | 5.13 | 5.99 | 4.25 | 3.44 | 3.10 | 0.25 | 5.81 | 4.12 |
| MnO | — | 0.11 | 0.04 | 0.04 | 0.10 | — | 0.05 | 0.04 | — | 0.09 | 0.05 |
| MgO | 0.43 | 1.36 | 1.26 | 0.41 | 2.25 | 1.36 | 1.04 | 2.10 | 0.09 | 0.41 | 1.14 |
| CaO | 1.02 | 3.66 | 2.62 | 2.07 | 4.46 | 3.43 | 2.90 | 5.25 | 2.33 | 3.25 | 3.33 |
| $Na_2O$ | 2.86 | 2.05 | 3.59 | 2.57 | 1.36 | 2.82 | 2.11 | 2.42 | 3.83 | 2.41 | 2.57 |
| $K_2O$ | 4.14 | 3.48 | 4.55 | 5.33 | 1.33 | 3.39 | 2.78 | 3.18 | 4.96 | 5.10 | 3.79 |
| $P_2O_5$ | — | 0.30 | 0.05 | 0.14 | 0.63 | 0.78 | 0.08 | 0.29 | 0.04 | 0.25 | 0.28 |
| BaO | — | — | 0.05 | — | — | 0.18 | — | — | — | — | — |
| S | — | — | 0.08 | — | $(SO_3)$ .27 | $(SO_3)$ .26 | — | 0.12 | — | — | — |
| $H_2O+$ | 0.20 | 0.67 | 0.28 | 0.29 | 0.19 | 0.38 | 0.29 | — | — | — | — |
| $H_2O-$ | 0.05 | — | 0.16 | 0.02 | 0.03 | 0.08 | 0.15 | — | — | — | — |
| NiO, $Cr_2O_3$ and $CO_2$ | — | — | Nil | — | — | — | — | — | — | — | — |
| Cl | — | — | Trace | — | — | — | — | — | — | — | — |
| Total | 100.59 | 100.01 | 100.71* | 100.02 | 99.57 | 99.89 | 99.82 | 99.83 | 100.33 | 99.50 | — |
| Spr. Gr. | 2.67 (Holland) | 2.86 | 2.85 | 2.75 | 2.89 | 2.80 | 2.71 | 2.74 | 2.63 | 2.71 | — |
| Classification | I.3''.''2.3 | II.(3)4.''3.3 | II.4.2.3 | (I)II.''4. (1) 2.3 | II.3.(3)4.3 (4) | II.3(4).3 (4).3 | (I)II.3''. ''3.3 | II.4.3.3 | I.(3)4.2.3 | II.3.3.3 | — |
| Location | St. Thomas' Mount, Madras | Haputale, Ceylon, surface of intrusion | 1 mile from Haputale Ceylon, 300 ft. from surface | Bulutota Pass, Ceylon | Hatton, Ceylon | Quarry, Nuwara Eliya Ceylon | P.W.D. Quarry, Galle, Ceylon | P.W.D. Quarry, Galle, Ceylon | 2 miles from Galle, Ceylon | Hedideni-kanda Quarry, Tillawel-mankada, Ceylon | |
| Analyst | H. S. Washington | H. S. Washington | R. J. C. Fabry | H. S. Washington | H. S. Washington | H. S. Washington | H. S. Washington | J. T. Donald | J. T. Donald | J. T. Donald | |

*Less O for S, 0.03% = 100.68.*

***Average composition calculated from the analyses of the eight Ceylon charnockites.*

TABLE II

ANALYSES OF ROCKS ALLIED TO CHARNOCKITES

| | A | B | C | D |
|---|---|---|---|---|
| $SiO_2$ | 51.24 | 67.34 | 71.74 | 55.40 |
| $TiO_2$ | .95 | .70 | .30 | 1.73 |
| $Al_2O_3$ | 19.74 | 17.01 | 11.13 | 18.70 |
| $Fe_2O_3$ | 5.10 | — | 2.96 | .72 |
| FeO | 6.38 | 5.35 | 1.70 | 7.29 |
| MnO | .14 | .08 | .53 | .15 |
| MgO | 2.64 | .72 | .55 | 2.12 |
| CaO | 7.52 | 4.48 | 3.42 | 8.25 |
| $Na_2O$ | 3.40 | 3.77 | 4.65 | 3.89 |
| $K_2O$ | 2.65 | .81 | 2.15 | 1.05 |
| $P_2O_5$ | .68 | .09 | .19 | .21 |
| BaO | — | — | .05 | — |
| S | .13 | — | $Li_2O$ trace | .12 |
| $H_2O+$ | — | — | .61 | — |
| $H_2O-$ | — | — | .05 | — |
| Total | 100.57 | 100.35 | 100.03 | 99.63 |
| Type of rock | Garnetiferous orthoclase norite | Rock intermediate between charnockite and quartz norite | Rock intermediate between charnockite and quartz norite | Rock intermediate between charnockite and hypersthene gabbro diorite |
| Classification | II. 5. 3. 3. | II. 2. 3. 4 | (I). II. 2(3). 1. 4 | II. 5. 4. 3 |
| Analyst | J. T. Donald | J. T. Donald | E. G. Radley | J. T. Donald |

NOTE: *Location: A, 12 miles from Colombo on the main road to Ratnapura, Ceylon; B, Village of Pussellawa, Ceylon; C, 3 miles southeast of Pussellawa, mile post 26; D, Nuwara Eliya.*

## GRANULITES OR LEPTYNITES

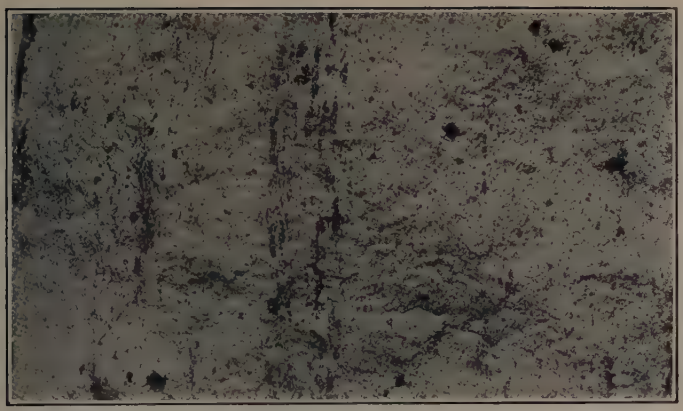
Seven typical granulites, or leptynites, from the numerous occurrences in Ceylon are here described as showing the character of the class as a whole.

Granulite—Road from Koslanda to Pottuvil, Mile Post 120.5

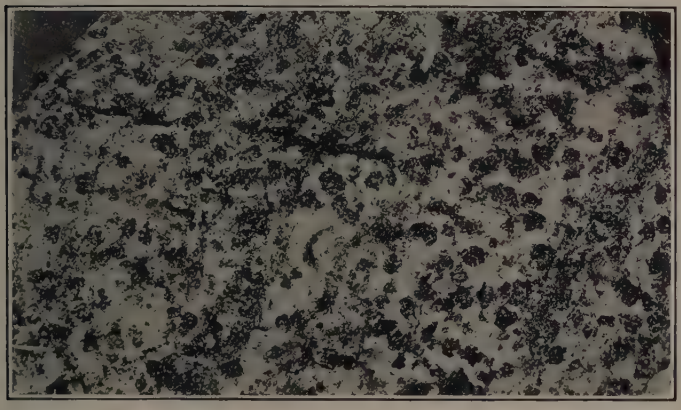
The rock is pale pink in color and shows a faint but distinct foliated structure. A photograph of a flat, freshly fractured surface of this rock is seen in Plate VIII (c).

Under the microscope it is seen to consist of a very minute allotriomorphic mixture of quartz and alkali feldspar, with a small amount of garnet and a very much smaller amount of biotite, iron ore and zircon.

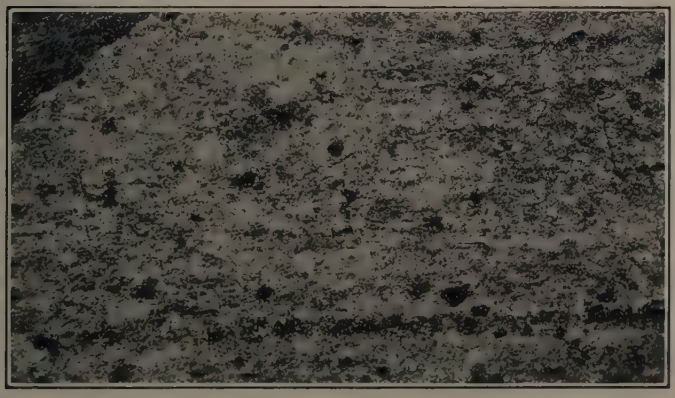
The feldspar is occasionally seen in simple untwinned individuals but is almost invariably in the form of microperthite, microcline and soda microcline. The quartz is in part in the form of allotriomorphic grains associated with the feldspar to form the mosaic of the rock and in part in the form of thin leaves lying parallel to one another and thus developing a foliation in the rock. The quartz leaves show a faint undulatory extinction. The garnet occurs in relatively large individuals sparsely scattered through the rock, irregular in outline, very pale pink in color and occasionally holding inclusions of the other minerals of the rock. The biotite occurs in minute flakes and the iron ore is titaniferous and partly altered to leucoxene. A few minute zircons are present.



(*a*) *White acid gneissic granulite—Galaha—Southern Ceylon.* (*Natural size*).



(*b*) *Garnetiferous sillimanite gneiss—Road between Bandarawela and Welimada—mile post 1.25—Southern Ceylon.* (*Natural size*).



(*c*) *Garnetiferous sillimanite gneiss—Road between Koslanda and Pottuvil—mile post 120.5—Southern Ceylon.* (*Natural size*).

## TABLE III

NORMS OF THE CHARNOCKITE ROCKS

| | I. A | I. B | I. C | I. D | I. E | I. F | I. G | I. H | I. I | I. J | II. A | II. B | II. C | II. D |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Quartz | 41.22 | 29.40 | 24.60 | 28.08 | 40.92 | 29.46 | 35.76 | 25.56 | 31.50 | 23.70 | 0.60 | 27.78 | 31.02 | 5.46 |
| Orthoclase | 24.46 | 20.51 | 27.24 | 31.14 | 7.78 | 20.02 | 16.68 | 18.90 | 29.47 | 30.02 | 16.12 | 5.00 | 12.79 | 6.57 |
| Albite | 24.10 | 17.29 | 30.39 | 22.01 | 11.53 | 23.58 | 17.82 | 20.44 | 32.49 | 20.44 | 28.82 | 31.96 | 39.30 | 33.01 |
| Anorthite | 5.00 | 13.90 | 2.22 | 4.73 | 18.63 | 11.68 | 13.62 | 20.29 | 1.67 | 11.12 | 30.30 | 21.41 | 3.06 | 30.02 |
| Hypersthene | 3.34 | 6.04 | 0.76 | 3.11 | 9.69 | 5.84 | 3.39 | 6.31 | — | 8.85 | 11.54 | 10.64 | — | 11.16 |
| Diopside | — | 1.86 | 8.59 | 4.34 | — | — | — | 3.40 | 0.43 | 3.66 | 2.29 | — | 5.01 | 8.35 |
| Magnetite | 1.62 | 2.32 | 3.71 | 0.70 | 1.16 | 1.39 | 4.41 | 3.02 | 0.93 | 0.23 | 7.42 | — | 4.41 | 0.93 |
| Ilmenite | 0.61 | 6.54 | 2.43 | 5.32 | 7.30 | 5.02 | 5.47 | 1.06 | — | 1.22 | 1.67 | 1.37 | 0.64 | 3.19 |
| Apatite | — | 0.67 | — | 0.34 | 1.34 | 2.02 | 0.34 | 0.67 | — | 0.34 | 1.68 | 0.34 | 0.34 | 0.34 |
| Pyrite | — | — | 0.11 | — | — | — | — | 0.22 | — | — | 0.25 | — | — | 0.26 |
| Corundum | — | — | — | — | 0.71 | — | 2.96 | — | — | — | — | 2.00 | — | — |
| Wollastonite | — | — | — | — | — | — | — | — | 3.94 | — | — | — | 2.90 | — |
| Subrang | Teham-ose | Harzose (Almer-rose) | Adam-ellose | Adam-ellose | * | Alme-rose | Alme-rose | Harzose | Tosca-nose | Alme-rose | Shosho-nose | * | * | Hessose |
| Classification | I.3".".2.3 | II". (3) 4".3.3 | II.4.2. 3 | (I)II."4 (1)2.3 | II.3(3)4. 3 (4) | II.3(4)3 (4).3 | (I)II.3". ".3.3 | II.4.3.3 | I.(3) 4. 2.3 | II.3.3.3 | II.5.3.3. | II.2.3.4 | (I)II.2 (3)1.4. | II.5.4.3 |

NOTE: *Each rock is designated by a Roman numeral and a letter indicating the table and column where its analysis is reported.*

**No name has yet been assigned to this division in the Quantitative Classification.*

The results of a chemical analysis of the rock is shown in Table IV. A; the norm in Table VI (IV. A).

The analysis does not show quite enough alumina to unite with all the potash and soda present to form orthoclase and albite—hence the presence of a small amount of acmite in the norm. No soda lime feldspar is present. The alkali feldspars are intimately intergrown as mentioned above. The mode or actual mineral composition of the rock is given in Table VII (III. A).

Granulite—Galaha near Kandy

The rock bears a very close resemblance to that just described, but is white rather than pink in color. It contains however less garnet and no other iron magnesia constituent. The orthoclase and albite occur in an exceedingly minute microperthitic intergrowth. The small amount of the anorthite molecule which the chemical analysis shows to be present must also be in this microperthite. Neither albite nor microcline twinning is seen in any of the feldspars. A very small amount of sillimanite is present. A photograph of a flat freshly fractured surface of this rock is seen in Plate VIII (a).

The rock consists essentially of microperthite and quartz with a very small amount of pale pink garnet and an occasional small individual of sillimanite.

The results of a chemical analysis of the rock are set forth in Table IV. B, and its norm in Table VI (IV. B).

In calculating the mode, if the garnet is taken as having the usual composition of an iron magnesia alumina variety, an excess of 1.2% of alumina remains, which if combined with the required proportion of silica, gives 2.40% of sillimanite and the following is obtained as the actual mineral composition of the rock. See Table VII (IV. B).

The percentage of sillimanite shown in this calculation of the mode is greater than that which appears in most of the thin sections, but may represent the average amount present in the rock.

Granulite—Two miles from Dambulla on the road to Sigiriya

This rock which occurs in large exposures about this point bears a very close resemblance to the two granulites just described. It is pale reddish in color and, like them, is composed essentially of quartz and feldspar with occasional grains of brownish-red garnet and a very small amount of biotite and iron ore in minute flakes and grains.

The feldspar is almost entirely orthoclase and albite intimately intergrown in the form of microperthite, associated with which is a very small amount of a soda lime feldspar. A few grains of micropegmatite are also seen in the thin sections.

Granulite—Road from Hambantota to Rakwana—Mile Post 87

This granulite, which occurs in heavy bands associated with white crystalline limestone, resembles very closely the three rocks just described.

On a fresh fracture it is pale pinkish, nearly white, and weathers to a rusty color. It is composed of microperthite, an acid oligoclase and quartz with a few grains of pink garnet and occasional grains of graphite and pyrrhotite.

The microperthite preponderates largely and but very rarely shows microcline twinning. Minute lines of limonite can occasionally be seen running between the feldspar grains and about the garnets, but a study of the thin sections does not clearly indicate the source from which this secondary mineral, giving rise to the rusty color of the weathered rock, is derived. The amount of pyrrhotite present would seem to be scarcely sufficient to account for this and the rock contains no other ferruginous constituents except the garnets.

It will be noted, however, that in garnet sillimanite rocks described elsewhere in this paper, the weathering of the garnet, which is a variety exceptionally rich in FeO, is the source of the limonite which stains the rock deeply on the exposed surface.

Granulite—Road from Nawalapitya to Dimbula—Mile Post 10

At this locality a white granulite is exposed. It is composed of microperthite, a soda lime feldspar and quartz, with biotite, iron ore, apatite and calcite as very subordinate accessory constituents.

Granulite—Road between Wattagama and Elkaduwa—Mile Post 10

Here there is a large quarry in a body of granulite resembling very closely those described above. As before, the feldspar is microperthite with a very small amount of soda lime feldspar. The only other constituents are the quartz with a small amount of garnet, a few flakes of biotite and still less zircon.

The granulite is here associated with beds of crystalline limestone and of quartzite.

Granulite—Near junction of the road between Ella and Haputale, with that to Badulla

This rock although related to the three last described differs from them considerably both in appearance and in composition. It is less uniform in character and lacks the minutely foliated appearance given to the other rocks by the small leaves of quartz which mark the plane of foliation. It represents a transitional form between true granulite and an ordinary garnetiferous gneiss.

The rock is grey in color with reddish garnets rather abundantly distributed through it and shows a rude foliation.

Under the microscope it is seen to be composed of quartz, orthoclase and a soda lime feldspar with a smaller amount of reddish garnet in irregular shaped individuals holding inclusions of the other minerals of the rock and a still smaller percentage of biotite, ilmenite, pyrite, apatite and zircon. The biotite is partly altered to a chloritic decomposition product and the ilmenite is partly altered to leucoxene. The orthoclase is in untwinned individuals, shows no microcline twinning and only traces of microperthitic intergrowth.

The results of a chemical analysis of this rock are given in Table IV. C; its norm and its mode are given under IV. C in Tables VI and VII respectively.

In calculating the mode as above, the regular formula for an iron alumina magnesia garnet has been used. It has been impossible to include the very

small percentage of chloritic decomposition product present, seeing that its composition is unknown. The combined water shown in the analysis is present in this chloritic material.

The pyrite included in the mode is seen in the thin sections, although the sulphur was not determined in the analysis of the rock.

TABLE IV

GRANULITES

| Constituents | A | B | C |
|---|---|---|---|
| $SiO_2$ | 76.25 | 75.70 | 68.54 |
| $TiO_2$ | .15 | .01 | .93 |
| $Al_2O_3$ | 11.16 | 14.34 | 13.69 |
| $Fe_2O_3$ | .34 | .50 | .07 |
| FeO | 1.38 | .19 | 4.66 |
| MnO | .45 | — | .53 |
| MgO | .11 | .25 | .81 |
| BaO | .05 | — | .18 |
| CaO | 1.16 | .87 | 2.89 |
| $Na_2O$ | 3.75 | 3.95 | 1.62 |
| $K_2O$ | 4.89 | 4.36 | 5.41 |
| $P_2O_5$ | .14 | .07 | .26 |
| $H_2O$ at 105°C. | .04 | — | .03 |
| $H_2O$ above 105°C. | .25 | — | .47 |
| Total | 100.10 | 100.24 | 100.09 |
| Type of Rock | Granulite | Granulite | Granulite |
| Classification | I. 4 (3). 2. 3 | I. 4 (3). 1 (2). 3 (4). | II. 4. 3 (2). 2 |
| Analyst | E. G. Radley | J. T. Donald | E. G. Radley |

NOTE: *Location: A, Road from Koslanda to Pottuvil—mile post 120.5; B, Galaha; C, road from Ella to Haputale, near junction with that to Badulla.*

## SILLIMANITE GARNET ROCKS (KHONDALITE)

Typical occurrences of these rocks from four localities have been studied in some detail.

### Road between Passara and Ella near Namanakula

The first occurs on the road between Passara and Ella just west of Namanakula, which is situated near mile post 12. The exposures are by the roadside and display a rather fine grained rock, dark reddish-grey in color, in which individuals of red garnet and minute prisms of glistening sillimanite can be distinguished. The rock has a banded structure, some bands being richer and others poorer in garnet, and it is interstratified with some thin beds of quartzite.

Coomaraswamy states that these rocks weather very readily and that it is "usually impossible to find them in anything like a fresh condition" owing to the fact that the garnets undergo peripheral decomposition with the development of limonite, the garnets falling out of the rock, so that a flat weathered surface becomes covered with a material resembling pisolite. The rock from

this locality shows this proneness to decay; it is stained with hydrated oxide of iron and it is extremely difficult to get specimens of it which are quite fresh.

Under the microscope the rock is seen to possess a more or less parallel arrangement of the constituents in the plane of its banding. The chief constituents are garnet, sillimanite and quartz. As accessory constituents there are small amounts of orthoclase, kaolin, iron ore, rutile and apatite. In thin sections the garnet is pale pink in color and occurs in elongated individuals arranged parallel to the foliation of the rock. It is traversed by minute films of hydrated oxide of iron, which is evidently an alteration product. The sillimanite occurs in stout prisms also arranged parallel to the general foliation and often partially wrapped around the garnet individuals. It shows the cleavage, extinction and other optical properties of the species. The orthoclase which is present in small amount is turbid in appearance owing to partial alteration to a mineral which is probably kaolin. The iron ore is present as a few black grains—in one section a few minute individuals of rutile are present.

A few small specimens of the rock showing only incipient traces of alteration were secured and one of these was analysed by Mr. R. J. C. Fabry in the laboratory of the Geological Survey of Canada. The results of the analysis are given in Table V. (A), the norm in Table VI. (V. A). The mode or actual mineral composition of this rock when calculated is found to be as given under V. A in Table VII.

The chemical analyses show the reason why this rock and the one next to be described weather so readily as compared with other garnetiferous rocks in Ceylon. It is due to the chemical composition of the garnet, which is an almandine in which the protoxide base is almost exclusively ferrous oxide, the mineral containing 33% of this base, which makes it highly susceptible to decomposition under tropical conditions. The garnets in other Ceylon rocks usually contain less ferrous oxide and more lime and magnesia.

Road between Passara and Ella at Mile Post 9.5

The second of these rocks is exposed at mile post 9.5 on the same road from Passara to Ella. It closely resembles that just described and is also interstratified with beds of quartzite. Under the microscope it is seen to be composed of garnet, sillimanite, quartz and an alkali feldspar, with accessory iron ore, rutile, apatite and limonite. In thin sections of the rock the garnet is pale pink in color and is traversed by minute cracks containing limonite as an alteration product. The sillimanite, quartz and iron ore present the usual characters of these minerals. Rutile is present in rudely prismatic forms, feebly transparent in deep brown tints and with parallel extinction.

Like the rock just described it shows a fairly distinct foliation and weathers to a deep rusty brown color. The alkali feldspar shows a minutely fibrous structure due to a fine microperthitic intergrowth of orthoclase and albite. A specimen of the freshest material that could be secured was analysed and its composition is given in Table V. B. The norm and the mode are given under V. B in Tables VI and VII respectively.

In making this calculation the garnet formula $3RO,Al_2O_3,3SiO_2$ is used, the 3 R O being the protoxide bases still remaining after satisfying the requirements of the feldspars, apatite and ilmenite. The titanic acid is arbitrarily divided between the ilmenite and rutile in the ratio of these minerals apparently present in the thin sections. An excess of 1.60% of water remains, unaccounted for and probably indicates the presence of a small amount of some hydrate of aluminum of the nature of bauxite associated with the limonite. If this be present it would slightly reduce the amount of sillimanite shown and slightly increase the amount of quartz, but the mode would remain essentially as shown.

Passara

The third of the sillimanite garnet rocks was found at Passara. At this village large beds of quartzite are associated with some garnetiferous gneiss and in the Administration Reports of the Mineralogical Survey of Ceylon limestone is mentioned as occurring here. This was not seen, and the inhabitants of the village knew nothing of its existence, although when crystalline limestone occurs in any district its presence is generally known to the Singhalese who burn it for lime. The limestone may lie in the bottom of the deep valley beside which Passara is situated.

The sillimanite garnet rock forms a bed 2 ft. thick immediately overlying the quartzite. It is pale grey in color and contains many individuals of pink garnet often having good crystal form and in some cases attaining a diameter of as much as 3 cm. The rock shows an indistinct foliation and is perfectly fresh.

Under the microscope the foliation of the rock shows distinctly and the rock is seen to be composed of quartz, microperthite, garnet and sillimanite as essential constituents with iron ore, rutile and a very little green spinel as accessory constituents.

The microperthite often shows the microcline twinning. The garnet holds numerous inclusions of quartz, iron ore, etc. The sillimanite occurs sometimes in long, slender individuals and sometimes in rather stout prisms, and presents clearly all the characters of this species. The iron ore is titaniferous and shows in places leucoxene as an alteration product. The rutile is feebly transparent with a deep brown color, and has the usual pleochroism with absorption $\mathfrak{e} > \mathfrak{o}$.

A chemical analysis of the rock shows that it has the composition set forth in Table V. C. The norm is given in Table VI; the mode in Table VII, both under V. C.

In calculating the mode, after setting aside the potash and soda for the feldspars, the remaining protoxides were used to make garnet, employing the regular garnet formula. All the ferric oxide was assigned to the garnet as the study of the thin sections show that practically all the titanic acid is present as rutile and not as ilmenite. The remaining alumina is united with silica to make sillimanite and the excess of silica is calculated as quartz.

TABLE V

ANALYSES OF GARNET-SILLIMANITE ROCKS

| | A | B | C | D | E | F | G | H |
|---|---|---|---|---|---|---|---|---|
| $SiO_2$ | 57.04 | 57.96 | 64.79 | 63.41 | 64.36 | 67.70 | 64.87 | 61.96 |
| $TiO_2$ | 0.10 | 1.38 | 0.89 | 0.25 | 0.81 | 1.22 | 1.63 | 1.66 |
| $Al_2O_3$ | 33.10 | 24.01 | 18.14 | 17.82 | 17.60 | 17.07 | 18.37 | 19.73 |
| $Fe_2O_3$ | 0.40 | 3.51 | 1.50 | 3.26 | 4.32 | — | 0.84 | — |
| FeO | 7.29 | 6.16 | 5.90 | 5.97 | 3.10 | 5.11 | 5.37 | 4.60 |
| MnO | 0.06 | 0.24 | 0.36 | 0.09 | — | 0.30 | 0.49 | trace |
| CaO | 0.75 | 0.68 | 1.07 | 1.13 | 2.39 | 0.47 | 0.62 | 0.35 |
| MgO | 0.73 | 1.05 | 1.33 | 1.94 | 2.48 | 2.10 | 2.22 | 1.81 |
| $K_2O$ | 0.47 | 2.13 | 2.92 | 3.81 | 3.85 | 2.89 | 3.01 | 2.50 |
| $Na_2O$ | 0.03 | 0.35 | 2.33 | 1.86 | 1.08 | 0.40 | — | 0.79 |
| $P_2O_5$ | 0.15 | 0.11 | 0.12 | none | — | — | — | — |
| $H_2O+$ | 0.44 | 2.17 | 0.65 | 0.22 | — | 2.60 | 4.20 | 1.82 |
| $H_2O-$ | 0.16 | 0.40 | 0.02 | 0.05 | — | — | — | — |
| Cl | trace | — | — | S .16 | — | — | — | — |
| BaO | — | none | none | 0.03 | — | — | — | — |
| $Li_2O$ | — | trace | trace | — | — | — | — | — |
| CoO,NiO | — | 0.02 | none | none | — | — | — | — |
| $CO_2$ | — | 0.02 | 0.01 | none | | — | — | — |
| Total | 100.72 | 100.19 | 100.03 | 100.00* | 99.99 | 99.86 | 101.62 | 99.55 |
| Rock | Garnet silli-manite rock | Garnet silli-manite rock | Garnet silli-manite rock | Garnet silli-manite rock | Palaeozoic shales** | Phyllite | Phyllite | Garnet silli-manite gneiss |
| Classification | II[2(3)] 1.4.1 | II[2] 2.2.2. | II3.2.3 | II 3.2.3 | — | — | — | — |
| Analyst | R.J.C.Fabry | E.G.Radley | E.G.Radley | R.J.C.Fabry | | | | N.N.Evans |

**Less 0.06 O for S=99.94.*

***Composite analysis of 51 samples, recalculated to eliminate $H_2O$, C, and $CO_2$ (15).*

NOTE: *Location: A, Road between Passara and Ella—m.p. 12; B, Road between Passara and Ella—m.p. 9.5; C, Passara; D, Road between Kandy and Aluinuwara—m.p. 24.5; F, Selgegrund near Wechselburg, Saxony (57); G, Penna, Saxony (57); H, St. Jean de Matha, Province of Quebec, Canada.*

Thirty-five Miles from Passara

The fourth garnet sillimanite rock is from a different part of Ceylon, being found about 35 miles from Passara in a northwest direction and about 15 miles in a straight line in a direction east-northeast from Kandy. The exposures are seen on the main road from Kandy to Aluinuwara.

At mile post 22.5 there are large exposures of beautifully fresh, rather coarse grained light grey gneiss with many streaks of pegmatite running parallel to its foliation. Both the gneiss and the pegmatite hold some garnet. The rock is composed of much quartz, orthoclase, sometimes with microperthitic intergrowths of albite, and garnet with small amounts of sillimanite, plagioclase, biotite and titaniferous iron ore. The road runs up a great valley of erosion, the same gneiss continues to be seen for the next two miles going west. At mile post 24.5, it is succeeded by large exposures of a rock which resembles it but is finer in grain and with a less distinct foliation. Under the microscope it is seen to be an allotriomorphic aggregate of quartz and orthoclase through which are distributed relatively large rounded individuals of pink garnet. Sillimanite is present in varying amount and small amounts of plagioclase, biotite, titaniferous iron ore, rutile, pyrite and zircon are also seen. The rock when analyzed was found to have the composition shown in Table V. D. Its norm is given in Table VI. (V. D).

TABLE VI

NORMS OF GRANULITE AND SILLIMANITE GARNET ROCKS

| | IV. A | IV. B | IV. C | V. A | V. B | V. C | V. D |
|---|---|---|---|---|---|---|---|
| Quartz | 33.54 | 33.96 | 28.56 | 46.92 | 42.54 | 31.92 | 29.46 |
| Orthoclase | 28.91 | 26.13 | 31.69 | 2.78 | 12.23 | 17.24 | 22.24 |
| Albite | 30.39 | 33.54 | 13.62 | — | 2.62 | 19.91 | 15.72 |
| Anorthite | — | 3.34 | 13.07 | 3.06 | 2.78 | 4.73 | 5.56 |
| Hypersthene | 0.66 | 0.70 | 9.32 | 14.74 | — | 12.14 | 12.42 |
| Ilmenite | 0.30 | — | 1.67 | 0.15 | 2.74 | 1.67 | 0.46 |
| Magnetite | — | 0.79 | 0.23 | 0.70 | 5.10 | 2.09 | 4.87 |
| Corundum | — | 1.70 | 0.40 | 31.40 | 20.20 | 9.40 | 8.67 |
| Diopside | 4.77 | — | — | — | 9.07 | — | — |
| Apatite | 0.34 | 0.34 | 0.67 | 0.34 | 0.34 | 0.34 | — |
| Pyrite | — | — | — | — | — | — | 0.40 |
| Acmite | 0.95 | — | — | — | — | — | — |
| Subrang | Toscanose | Liparose | —* | —* | —* | —* | —* |
| Classification | I.4(3).2.3 | I.4(3).1 (2).3 (4) | II.4.3 (2).2 | II.[II(III)] 1.4.1 | II[II] 2.2.2 | II.3.2.3 | II.3.2.3 |

NOTE: *Each rock is designated by a Roman numeral and a letter indicating the table and column where its analysis is reported.*

**No name has as yet been assigned to this division in the Quantitative Classification.*

TABLE VII

MODES OF GRANULITE AND SILLIMANITE GARNET ROCKS

| | IV. A | IV. B | IV. C | V. A | V. B | V. C |
|---|---|---|---|---|---|---|
| Quartz | 33.54 | 33.82 | 30.12 | 30.36 | 30.96 | 27.42 |
| Orthoclase | — | — | 31.14 | 2.78 | 12.23 | 17.24 |
| Microperthite | — | 63.01 | — | — | — | — |
| Microcline, soda microcline and microperthite | 59.30 | — | — | — | — | — |
| Soda lime feldspar | — | — | 26.69 | — | — | — |
| Albite | — | — | — | — | 2.62 | 19.91 |
| Garnet | 6.39* | 1.76 | 7.58 | 20.55 | 18.90 | 22.05 |
| Sillimanite | — | 2.40 | — | 43.06 | 27.18 | 11.62 |
| Biotite | — | — | 1.18 | — | — | — |
| Ilmenite | 0.30 | — | 1.73 | — | 0.76 | — |
| Limonite | — | — | — | 0.49 | 4.11 | — |
| Pyrite | — | — | 0.30 | — | — | — |
| Apatite | 0.34 | 0.24 | 0.61 | 0.33 | 0.34 | 0.34 |
| Rutile | — | — | — | — | 1.00 | 0.89 |
| Kaolin | — | — | — | 2.55 | — | — |

*Contains a little biotite.

## CRYSTALLINE LIMESTONES

These limestones resemble in a most striking manner the great limestone bands of the Grenville Series in the pre-Cambrian of the Canadian Shield. The distribution and geological relations of these rocks are described elsewhere in this paper, here it is proposed to refer only to their petrographical character and to confine the consideration of this to certain of the larger and more important occurrences.

### White Crystalline Limestone—Road between Kandy and Weregama—near Mile Post 42

This rock is coarsely crystalline and occurs in very large exposures. It effervesces freely with cold dilute hydrochloric acid.

When examined under the lens it is seen to be composed of an aggregate of grains of calcite and dolomite. The dolomite has a slight brownish tint which is due to the incipient alteration of a small amount of ferrous carbonate present in the dolomite molecule. The calcite is white. When thin sections are stained with Lemberg's solution and examined under the microscope it is seen that while the two carbonates are intimately associated, this association is not the result of a simultaneous crystallization of the two minerals. It is due, in part at least, to a replacement of the calcite by the dolomite. From the individuals of the latter mineral long narrow lath-shaped fingers or laths can often be observed extending into the calcite. The two minerals are not in parallel crystallographic position, for if they were they would extinguish simultaneously in all sections, which is not the case. In fact they have not a regular or constant crystallographic relationship. A single "lath" of dolomite can often be

observed traversing two or more grains of calcite in succession, which grains are differently orientated. There is, however, a tendency for these dolomite "laths" to traverse the calcite individuals either (1) parallel to the basal plane of the calcite, (2) parallel to the rhombohedral cleavage planes, or (3) on the twin planes—½ R.

This intimate association of the same two minerals in certain occurrences of crystalline limestones from Ceylon has already been mentioned and figured by Coomaraswamy in an important paper on these rocks which appeared in 1902 (29). He refers to the "intergrowth" of the two minerals parallel to the basal plane, but also refers to "ramifying intergrowths" in which what he terms the "fingers" of dolomite pass through several calcite grains having different orientations. It will thus be seen from the cases described in the present paper, as well as those referred to by Coomaraswamy, that the relationship of the dolomite and calcite is not that of a true crystallographic intergrowth, except in a few chance instances. Coomaraswamy also observes that, "In many of the parallel intergrowths the calcite and dolomite are of equal relative importance: in others and in most of the ramifying intergrowths we usually find the calcite predominates and should speak of the dolomite as forming parallel or ramifying inclusions in the calcite; it is exceedingly rare to meet with the reverse relation".

In the collections of rock specimens made by Leschenault de la Tour in Ceylon and India in 1820 and studied by M. le Comte de Bournon (10) and, many years later, by Lacroix (44), there were crystalline limestones from near Kandy and from two other localities in Ceylon. The first of these latter is stated to be seven "lieues" east of Kandy. If this be taken as equivalent to seven English leagues it is about the position of the great limestone belt from which the specimens here described were taken. Lacroix describes the rock collected at this locality as composed of irregularly shaped individuals of a normal dolomite cemented together by calcite. He states that the dolomite occurs in the calcite in the same forms as those assumed by the "quartz de corrosion" when occurring in feldspar and suggests that the calcite is of secondary origin.

There are certain accessory constituents present. The most important are forsterite and pyroxene while phlogopite, pyrite and garnet are less abundant, the latter being rarely seen in the thin sections.

The forsterite is more abundant than the pyroxene and occurs in colorless rounded grains. They show a fairly good cleavage with parallel extinction and are optically positive. The pyroxene is also colorless and has the characteristic cleavages and an extinction angle of 33°. It occurs in comparatively large individuals or in finely crystalline aggregates and in some places shows a tendency to develop about the margin of the forsterite grains, although not showing the remarkable zonal arrangement described in the crystalline limestone which occurs 1.5 miles north of Badulla on the Taldenia Road.

White Crystalline Limestones—1.5 Mile north of Badulla on the road to Taldenia

The great exposures of this rock which are so excellently seen on the east of the road at this point bear a striking resemblance to the great beds of crystalline limestone in the Grenville Series in Canada. Even the black color of the weathered surface, so often seen in the Canadian occurrences, and which is probably due to some minute vegetable growth is here reproduced.

The marble occurs in long ridges. It is nearly pure and is coarsely, often very coarsely, crystalline.

Of the specimens collected the majority proved to be composed of dolomite and showed no effervescence with dilute acid, except at one or two spots where a very small amount of calcite was present. A few specimens however were found to be composed of calcite.

The rock is here quarried and burned for lime, the bands richer in calcite probably being selected for this purpose. The rock contains in places a little phlogopite and pyrite and some bands are quite rich in forsterite. This latter mineral in the hand specimen has a dark bluish-grey color. In thin sections it is colorless and has the form and optical properties already mentioned as characterizing the occurrences of this mineral in the other limestones described in this paper. In several of the thin sections of this rock the forsterite individuals are surrounded by a narrow zone of pyroxene consisting of minute prisms closely packed together in parallel position and arranged at right angles to the surface of the forsterite, forming a "reaction rim" as described in the limestone from Sigiriya. As in that rock these minute prisms show a cleavage parallel to their longer axis with an extinction of 30°, and when suitably cut the revolving bar of a biaxial crystal. In cross section under a high power the prisms can be seen to be nearly square in cross section. In all the cases observed the forsterite was enclosed in one or more individuals of dolomite, the pyroxene zone separating the two minerals from one another.

An exhaustive account of our present knowledge of the curious phenomena of reaction rims has been given by J. J. Sederholm (59). In this excellent paper, which contains a very complete review of the literature of the subject, the only occurrence of a corona-like arrangement, analogous to that here described, in a rock which may be considered to be of sedimentary origin, is that described by Lacroix (p. 60 of Sederholm's book) where in certain crystalline limestones from Ceylon, individuals of chondrodite which are altering into calcite are surrounded by a narrow zone of serpentine which is subsequently itself replaced by calcite.

This alteration of pyroxene, chondrodite and other magnesian silicates into serpentine is very widespread where rocks containing these minerals are in the process of alteration or decay. In the crystalline limestones of the Grenville Series of the pre-Cambrian of eastern North America, no accessory mineral is more abundant than serpentine, which occurs in small rounded grains. As a general rule these grains, while manifestly the products of alteration of some

other mineral, contain no remnants of the original mineral within them, the alteration having been complete. When very large lumps of this serpentine are found and are broken open they are often seen to contain round nuclei of a white pyroxene, from the alteration and hydration of which they have been produced, and which indicate the source or origin of all this serpentine (6, 49).

In the case of the pyroxene zones about the forsterite in the rock under consideration a somewhat different phenomenon is seen, it is not a case of hydration nor is pyroxene a mineral which occurs commonly as an alteration product. The metamorphic process through which this rock has passed has apparently gone forward in successive stages. First the crystallization of the calcareous sediment into an aggregate of calcite and dolomite, or possibly the crystallization of the rock into calcite and its subsequent dolomitization. Some of the dolomite at least is, as has been shown, later than the calcite. Whether the forsterite was produced at the same time by the combination of silica and magnesia in the original sediment or whether it was developed by subsequent metasomatic action is uncertain. A forsterite individual is frequently seen to be completely enclosed in a single crystal of dolomite, which might be regarded as indicating that it was formed before the latter mineral, but on the other hand, in limestones near great bodies of intrusive rock in the Grenville Series in Canada minute rounded individuals of pyroxene can frequently be observed, which with increased intensity of metamorphism increase in size and develop into large and perfect crystals, apparently owing to the transfusion of silica from the adjacent intrusives. Finally in the case of the rock at present under discussion, it would seem that the radially arranged pyroxene prisms around the forsterite have been due to reaction between the magnesia iron silicate (forsterite) and the lime magnesia carbonate (dolomite) with the production of a lime-magnesia-iron silicate (pyroxene) lying between them. The appearances lend support to the view that the pyroxene zone has been formed at the expense of the forsterite individual as this latter is small in size when the pyroxene zone is wide.

White Crystalline Marble—One-third of a mile North of Mile Post 10 on the road between Wellawaya and Pottuvil

This occurs in the form of a band interstratified in the gneiss about one-third of a mile north of the road.

It is a pure coarsely crystalline dolomite showing no effervescene with cold dilute acid and being free from all impurities.

Road between Pelmadulla and Haldummulla, near Mile Post 101

In the bottom of the valley of a little stream which crosses the road at this point a rather impure white crystalline limestone is exposed, which was formerly burned for lime here. It is of medium grain and most of it effervesces freely when treated with dilute acid, showing that it is composed of calcite, there are however in it streaks of dolomite and in some places inclusions of a pale grey

pyroxene rock altering into serpentine. The rock also contains minute flakes of phlogopite and grains of diopside scattered through it, the latter in thin sections showing its characteristic cleavages, biaxial character and an extinction angle of 44°.

White Crystalline Limestone—Railway Cutting near Habarene

The limestones in these great exposures are referred to again in the section dealing with the distribution and relations of the Archean rocks.

The rock effervesces freely with dilute acid, being composed chiefly of calcite. Some dolomite is present and is intimately associated with the calcite in the manner already described in the case of the crystalline limestone on the road between Kandy and Weregama. Several of the usual accessory minerals are present, of which the most important is olivine, which in this rock has a large axial angle and is negative in sign, showing that the mineral contains more than 12% of ferric oxide.

This olivine however is always decomposed into a fine grained aggregate of serpentine and rhombohedral carbonates, only small remnants of the original olivine remaining in some of the larger individuals.

White Crystalline Limestone from the Fort at Sigiriya

The remarkable butte of gneiss rising from the coastal plain, on which the Fort at Sigiriya was built, is described elsewhere in this paper. The steps of the stairways leading up to the higher portion of this rock as well as a part of the pavement on the hill top are constructed of a white crystalline limestone or marble, which was quarried at a point in the jungle about six miles in an easterly direction from the butte. The rock is a white marble of medium grain composed of a mixture of calcite and dolomite. These minerals often show a tendency to occur in indistinct alternating bands. Under the microscope the two minerals are seen as a rule to occur as separate individuals, but in a few instances narrow laths of the dolomite can be observed traversing calcite grains in a direction parallel to the basal plane. The relation of the two minerals is clearly seen in sections stained with Lemberg's solution. Some of the grains of these carbonates are clear, while others are more or less turbid. These differences do not characterize either species. The same individual is frequently turbid in one part and clear in another.

In the thin sections a good deal of forsterite is seen to be present as an accessory constituent. This occurs in rounded or prismatic forms and presents the characteristic optical properties of the species. Occasionally it is altered to serpentine. Partially or completely encircling, some but not all of the forsterite individuals is a zone of minute colorless individuals of pyroxene, which occupy an approximately parallel position and stand out at right angles to the surface of the forsterite individuals which they surround. These present exactly the appearance of the "reaction rims" seen in certain plutonic igneous rocks. The minute pyroxene individuals forming these borders show a cleavage parallel to the length of the prism with an extinction of 30° against it.

They have a rather high index of refraction and double refraction, and when seen in cross section appear to have an octagonal section. The phenomenon of these interesting "reaction rims" has already been referred to in describing the crystalline limestone which occurs 1.5 miles north of Badulla on the Taldenia road, in which rock they are seen in still greater perfection.

White Crystalline Limestone used as road metal about Nalunda

Two varieties of this were examined. The first is very pure and rather coarsely crystalline. It will not effervesce with dilute acid and is a dolomite. The second, which is less pure, is a mixture of dolomite and calcite, the former mineral preponderating. The impurities consist of a pale green mineral, either olivine or pyroxene, with a little serpentine and still less pyrite.

Crystalline Limestone—Road from Dambulla to Matale—Mile Post 37.5

There are great bands of white crystalline limestone running in a general north and south direction through this district, and at this locality there is a large quarry in the limestone which affords excellent exposures of the rock. The bedding of the rock is emphasized by darker bands which are more or less impure owing to the presence of various silicates which they contain.

The limestone consists chiefly of calcite as shown by the fact that the greater part of the rock effervesces readily with dilute acid. Mingled with this calcite there are, however, grains of dolomite which are in some cases separate individuals and in other cases are intergrown with the calcite. The relative amount of dolomite present varies in different bands.

The silicates present in the specimens examined are olivine (probably forsterite), phlogopite and serpentine.

The forsterite occurs in rounded individuals often showing a tendency to prismatic development, with one cleavage parallel to the longer axis of the prism and to which the extinction is parallel. The mineral is biaxial with large axial angle. The serpentine is derived from the alteration of this forsterite.

Crystalline Limestone—Getembe, near Kandy

This is one of the best known occurrences of this rock on the Island. It forms large exposures on the road between Kandy and Peradeniya at Getembe, where it is quarried. It forms a well defined bed with a steep dip and having a thickness of at least 200 ft. The rock underlying it is not seen but it is overlain by a pale grey quartzose gneiss with flakes of biotite and numerous little red garnets. A large part of the band consists of a very coarsely crystalline and nearly pure white dolomite. The remainder consists of impure streaks in which the dolomite is associated and intergrown with calcite, or others of calcite and forsterite for the most part altered to serpentine, or others again in which the carbonates are practically absent and the rock is nearly black and composed of deep brown hornblende, a light green pyroxene with much red garnet, with small quantities of plagioclase, hypersthene, biotite and black iron ore as accessory constituents.

The rock is burnt for lime in a kiln by the side of the quarry, being broken into pieces about the size of a walnut and thrown into the kiln with small sticks and fragments of waste wood, which give rise to a smouldering fire. The lime is raked out between the grate bars at the bottom of the kiln from time to time. This quicklime is slaked in a large bin and is all sold to the Singhalese who mix it with ground areca nut and having wrapped the mixture in betel leaves, chew it. To a denizen of the western world it is rather appalling to think that such a tonnage of slaked lime is to be disposed of in this manner.

White Crystalline Limestone about 1.5 miles northeast of Wellawa

This occurs in an area of very flat country and has been uncovered by large shallow excavations made in the paddy fields. The rock is a coarsely crystalline aggregate of calcite individuals, effervescing freely with dilute acid and presenting a mottled appearance, in white and pale brown colors. These respective colors are not confined to different individuals but are often seen in different parts of the same crystal. The rock contains very few impurities and is quarried both for road metal and for the production of lime.

Magnesite

This mineral has been discovered at two localities, in association with bands of crystalline limestone.

The first locality is at Randeniya, Wellawaya (See Analysis B, Table VIII).

TABLE VIII

ANALYSES OF LIMESTONES—CEYLON

| Constituent | Composition per cent | | | |
|---|---|---|---|---|
| | A | B | C | D |
| CaO | 30.41 | 1.31 | 50 | 52 |
| MgO | 20.98 | 47.60 | 2 | 1.5 |
| $Fe_2O_3$–$Al_2O_3$ | 0.70 | traces | — | — |
| $SiO_2$ | 3.20 | 0.50 | 2 | — |
| $CO_2$ | 43.54 | — | 42 | 42 |
| $P_2O_5$ | — | 0.09 | — | — |
| Ignition ($CO_2$ or $H_2O$) | — | 50.52 | — | — |
| $H_2O$ | — | — | 2 | 2.5 |
| Loss | — | — | 2 | 2 |
| Total | 98.73 | 100.02 | 100.00 | 100.00 |

NOTE *A. Massive White Crystalline Limestone—Diyaluma Falls, Koslanda (Mineralogical Survey of Ceylon, 1906-7 and 1907-8, H.M. Stationer's Office, No. 74); B. White Crystalline Magnesite—Randeniya, Wellawaya. (Mineralogical Survey of Ceylon, 1906-7 and 1907-8, H.M. Stationer's Office, No. 74); C. "Granular Foliated Limestone"—Kandy—"Analyses made in Colombo of Ceylonese Varieties of Ironstone and Limestone", by George Middleton, Esq., Apothecary to the Forces. (Edin. New Phil. Jour., IV, 1828, p. 169); D. "Common Compact Limestone"—Poaeloor Cavern, near Jaffna. (Edin. New Phil. Jour. IV, 1828, p. 169).*

At the second locality a deposit of hydromagnesite was found. This is in a cave in crystalline limestone at Maturata. This deposit was first mentioned by Davy, a brother of Sir Humphrey Davy, who visited Ceylon in the early years of the 19th Century, and has been examined more recently by Parsons (53). The deposit is a small one but the material is in demand for the purpose of painting the walls of Buddhist shrines.

Analyses of Crystalline Limestones from Ceylon

Only four (partial) analyses of these rocks have been published. These were made many years ago and are given in the accompanying table (No. VIII).

Modder (50) states that "the purer forms of crystalline limestone and dolomite in Ceylon contain respectively 1.77 to 2.51 and 19.33 to 26.00% of carbonate of magnesia."

## The Geological Structure of the Island

The Island of Ceylon, as has already been mentioned, presents a low coastal plain from which there rises rather abruptly, in its south central part, a great massif of ancient crystalline rocks, the highest point of which—Pidurutalagala—reaches an elevation of 8,292 ft. These ancient crystalline rocks are not confined to this higher land but extend under the coastal plain, which is incised in them.

The coastal plain is very narrow on the south coast and on the southern half of the west coast, but becomes broader on the east coast, while to the north it widens out and forms the greater part of the northern half of the Island. The whole coastal plain in the Jaffna peninsula and in the adjacent part of the northern end of the Island is covered by deposits of miocene age, to which reference is made in another part of this paper, and deposits of this age have also been found at one or two points on the sea coast in the southern and eastern parts of Ceylon. Other sedimentary deposits, probably of still more recent age, occur in places elsewhere along the coast and together with the residual deposits resulting from the decay of the crystalline rocks themselves, serve over considerable areas to mantle and hide the ancient underlying crystalline rocks of the Archean.

Confining our attention to these crystalline Archean rocks, it may first be noted that a study of this Archean area shows that it possesses a very interesting geological structure.

Although the rocks composing it are of many kinds and of diverse origin they display, more or less distinctly and practically everywhere, a foliated or a banded structure—that is to say while they are completely crystalline, their constituent minerals, or some of them, show a tendency to parallel arrangement ("foliation"), or the individual rock varieties, such as the marbles, quartzites, etc., have the form of beds or bands, within which there may also be a foliation which beds conform in strike to the direction to the foliation of the associated gneisses. By tracing the course of the foliation (or banding) throughout

the area the structure of the latter is clearly revealed. While the strike of the foliation was ascertained by actual observation over the greater part of the area, additional information concerning the strike of the gneiss in many districts was obtained by a study of the excellent topographical maps on a scale of one mile to the inch with contoured intervals of 100 ft., which have been prepared by the Surveyor General's Department of Ceylon. The relief of the country has been developed by a process of secular decay through untold geological time, which has in all the more highly accentuated part of the area developed ridges or lines of buttes whose direction is determined by the strike of the crystalline rock of which they are composed and which over many parts of the area stand out on these maps with diagrammatic clearness.

Another element which is of special value in working out the structure of the Archean area is the presence of certain bands of crystalline limestone. These conform to the course of the foliation of the associated gneissic rocks in all its windings, but being very distinctive in character form excellent horizons to follow. Here as elsewhere in areas of crystalline rocks, these limestones have the disadvantage that owing to the fact of their ready solubility they are apt to lie in depressions and thus be more or less concealed by surface wash. When concealed, however, their position can often be determined from the strike of the associated gneisses.

In the Island there are two of these limestone bands which are of especial importance in deciphering its structure. These may be called the Badulla and the Matale bands, respectively, from the towns of these names at which they are well exposed.

Commencing on the west side of the Island, the Badulla limestone band is first seen at Mimure near Morawake. This place is about six miles west of Kegalla and here the limestone is being extensively quarried. This is the most westerly occurrence of crystalline limestone in the Island. The extension of this limestone band to the north has not been followed, the country in this direction presents a series of low ridges with paddy fields, scrub and "chena" between them, these ridges becoming fewer in number and lower in altitude as the boundary of the Miocene area is approached. The band probably finds its continuation under one of these strips of lower land. Following the band to the south it is seen crossing the road between Morawake and Kegalla, and has been observed again 3.5 miles from this road at Eratana and then, following the strike which swings slowly toward the southeast, at Kudawa, Bambarbotuwa (18) and Hunewela. The strike now veers to the east and the limestone is exposed on it at Rassagala and then near Balangoda. Here it swings to the northeast and the limestone is exposed at Haldammulla. The strike then changes in direction to east and west and the band is seen along the base of the great precipice immediately to the south of Haputale, about Koslanda and to the east of that place. The strike then swings around to the northeast and the band is exposed at Randeniya and then around the foot of the continuation of the great escarpment above mentioned to Badulla and Taldenia, where it is seen in great exposures which have been mapped by

Coomaraswamy (17). Here the limestone is developed as a large band showing a subordinate synclinal fold, with a smaller one immediately to the west of it and following a parallel course. The strike here is a little to the west of north and the limestone is seen in great force in the valley of the Manaweli Ganga at Weragamtota, where it is exposed for 120 yards across the strike and to the east passes under a great paddy field beneath which it undoubtedly expands to a still greater width. This valley, walled by a precipice on the west, runs directly north on the strike of the country rock for several miles, the limestone continuing to follow it. The country then becomes low and no rock exposures are seen. The band must pass beneath low land to the west of the ancient city of Polonnaruwa, after which the strike swings at first gradually and then sharply to the northeast, bringing the band to Trincomalee, where it is again exposed.

The second or Matale limestone band is situated toward the centre of the Island and in its northern extension is first seen at the Mahakandarawa Tank, about four miles east of Mihintale. To the north there is low land beneath which the limestone passes. To the south the land is also low with few exposures, beneath this the band following the strike of the country rock must pass a short distance to the west of Dambulla. It comes to view again just north of Nalanda and then is continuously exposed along the road to Matale and thence following the curving strike to the southeast to Wattegama, up a synclinal fold to Hanguranketa and on to the outskirts of Hewaheta. About Mailapaitiya this limestone band plunging to the north divides on the axis of the syncline, the other branch running off in a westerly direction toward Kandy. It has been mapped in the district to the southeast of that city by Coomaraswamy (29). It is again seen in large exposures at Getembe between Peradeniya and Kandy, after which its course is unknown.

A third important development of crystalline limestone in the Archean area of Ceylon is that which is seen in the extreme south of the Island in the Rakwana district. This village is situated immediately to the north of the large isolated body of charnockite on the Bulutota Pass. Here a number of parallel limestone bands are found interstratified with the gneiss, as shown on the accompanying map. At Rakwana they strike east to west. To the west of this place the strike of the country rock swings around to a northwest course, but the country becomes lower and covered with a thick mantle of residual soil and the limestones are not seen again unless indeed the occurrence at Kuruivita belongs to one of them. To the east of Rakwana the strike makes a great curve to the southeast being part of a graceful festoon on the garland formed by the gneiss as it sweeps around the Island, and runs directly toward the shore under low land with but few exposures passing into the sea to the west of Hambantota.

It might be supposed from an examination of the map that these limestone bands would be carried around by a continuation of this curve beneath the sea, and reappear in the southeastern part of the Island. The writer has not examined that part of the Island south of the road running east from Wellawaya

to Pottuvil on the east coast, nor has the geology of this area been examined by anyone so far as can be ascertained. A study of the topographical map of this part of the Island, however, shows this area to be low land from which there rise here and there low scattered rock buttes. These are undoubtedly of gneiss. The map, however, records in the case of about fifteen of these buttes, whose position is indicated on the accompanying map by small blue crosses, that they contain a cave. In Ceylon, as elsewhere, caves are generally, although not always, formed by the solution of limestone, and this may be their origin here. If such be the case, the distribution of the caves would indicate the presence of a number of small separate bands of limestone, as in the Rakwana district. It may therefore be found on further investigation that a series of small limestone bands, the continuation of those at Rakwana, pass again into the Island from the sea and run up to the north under this low land and parallel to the east coast.

There are certain other isolated occurrences of crystalline limestone on the Island which may be mentioned in order to complete the list of those which have been observed and recorded up to the present time. The most easterly of these is in the jungle about one-third of a mile north of Buttala on the road from Wellawaya to Pottuvil, a village situated on the east coast of the Island. Here there is a large exposure of white coarsely crystalline dolomite associated with banded gneiss in the bed of a little stream. This may find its continuation in another occurrence of the same rock a short distance south of Bibile. The writer was informed by a native that limestone was also found in the jungle at a point about one and a half miles west of the occurrence near Buttala.

A very wide band of white crystalline limestone holding olivine and other minerals is cut by the Trincomalee Railway immediately to the east of the point where this railway crosses the road between Dambulla and Trincomalee. This is not far from Habarane. The band is exposed in the railway cutting for a width of 325 yards and shows a series of gentle undulations with very low dips. Eight miles from this occurrence, in a direction to the east of south, another large body of similar limestone is exposed at Dikkandaeia, about four and a half miles east of the great rock fortress Sigiriya. This may be a continuation of the limestone near Habarane, although the average strike of the country rock would carry the latter somewhat to the west of the point above mentioned. Following along the strike to the south, limestone again appears at the Nitre Cave, 16 miles from Matale in a direction somewhat south of east. It is not known whether this is connected with the limestones to which reference has just been made.

A group of very important occurrences of limestone is found in the district to the southeast of Nuwara Eliya. The first of these is at Hakgala and is exposed on the road from mile post 54.5 to mile post 57. Its distribution about Hakgala has been mapped by Coomaraswamy (29). Large occurrences of the same rock are again seen further along the same road to Welimada at mile post 68¼. The strike of both of these limestones is to the west of north and they are separated by bands of gneiss. The rocks about here are however

much folded. In one fine exposure at mile post 5 on a road leaving the main road just mentioned near Hakgala and running to Ambawela, a band of white quartzite interstratified with gneiss is seen to be completely folded back on itself in the form of a great oval shaped hoop (see Plate VII (c)). Whether these limestones form part of one and the same band repeated by folding must be left for further study to determine. Limestone is again exposed on this high plateau near Ella and again near the Rest House at Pussellawa. Other exposures have been recorded at Watagoda and Dolosbaga. These the writer has not seen but the rocks about the latter place lie in a broad syncline in low undulations and nearly flat. From the general direction of this syncline Dolosbaga, on the north, may also lie within it. (See Section). Many beds of white quartzite are exposed in this district so that the presence of associated limestone bands might be expected. It may prove on further investigation that these limestone-quartzite occurrences occupy the same horizon as the limestones at Hanguranketa. At Palpata about five miles east of Kegalla, where the limestone is extensively quarried, also at Wellawa, about six miles from Kurunegala in a direction a little east of north, where an extensive occurrence of coarsely crystalline limestone has been laid bare by excavations in the paddy fields and is worked for road metal and for the production of lime. The position of these occurrences with reference to others suggests in certain cases that they form parts of the same band, but until this has been established it has seemed better merely to indicate their respective positions on the map.

The geological structure of the Island is clearly shown on the map which accompanies this paper. The strike of the gneisses, conforming everywhere to the course of the limestone bands which are found in them, is in its main outlines parallel to the coast line. In the northwestern part of the Island, where the gneisses appear from beneath the overlying mantle of Miocene strata, the strike is a few degrees to the east of south. Maintaining this course down the west side of the Island till about the latitude of Colombo, it then slowly sweeps round to the southeast, then following an east to west course runs in a series of graceful undulations across the southern part of the Island and, sweeping first to the northeast and then to the north, it again assumes its north and south course until it reaches the latitude of Anuradhapura, where on the eastern half of the Island it veers round to the northeast and following this course passes out to sea in the Trincomalee region, while on the western half of the Island it maintains its northerly course, so far as the few scattered exposures of gneiss enable this to be determined, until it passes beneath the Miocene. On the east coast between Batticaloa and Pottuvil the strike swings gently outward to the east and turns again to the west to conform to the general north and south course. To this local deflection in the course of the strike of the gneiss is due the outward bulge to the east which the Island here displays and which gives to it the pear-like form which one of its distinctive characters.

The strike of the gneiss thus takes the form of a series of graceful garlands pendant as it were from the northern apex of the Island. In the extreme south, in the area to the northeast of Hambantota, a festoon adorns the garland. About Rakwana the gneisses with their limestone bands suddenly change their course and strike to the southeast instead of following the prevailing east and west direction, which carries them beneath an area of low covered land with few or no exposures. In this area therefore no strikes are shown on the map because they have not been observed. From the course of the gneiss on the east, north and west sides of this low area it seems probable that the Rakwana limestone and their associated gneiss pass into the sea about Hambantota and it is probable that, conforming to the general plan, they follow beneath the sea, a course parallel in a general way to that of this portion of the southern coast and reappear in the Eastern Province of the Island, running with a strike a little to west of north through that belt of country in which, as has been mentioned, so many caves have been recorded by the Topographical Service, thus completing the structural pattern of the Island.

Speaking generally, the gneisses on the west side of the Island dip to the east, while those at the east side of the Island dip to the west. The dip on the west side of the Island, especially near the coast, is generally at very high angles, often nearly or quite vertical, or occasionally even overturned slightly, while on the east side the dip to the west is lower, dips of 40 to 60 degrees prevailing, while as the east coast is approached, the dip sinks to angles of 30, 20 and even 15 degrees.

The Island is thus a great syncline whose axis runs throughout its length, in a general north to south direction, passing a short distance to the east of Kandy and of Nuwara Eliya.

This syncline is closed on the south by the great sweep of the strata around the southern part of the Island here dipping everywhere, inward, that is to the north, but it is open to the north where the strike of the gneiss before sinking beneath the low land covered by Tertiary deposits commences to open out, as has been mentioned, into a trumpet-like form. This great syncline of archean rocks which constitutes the Island of Ceylon thus plunges to the north and disappears beneath the Miocene strata which occupy the northern end of the Island.

In the extreme southwestern portion of the Island there is a low anticline, the axis of which takes its rise on the east at a point about half-way between Rakwana and the south shore of the Island, the westerly dip continuing all around the eastern and southern coast and up the west coast to an inland point east of Kalutara. Here the anticline ends, the dip becoming vertical or nearly so, thus conforming in attitude to that seen throughout the western part of the Island further north.

In the high lands of the interior of the southern half of the Island the great syncline displays along its central axis several minor parallel folds. These are well seen in the geological section across the Island which accompanies this

paper. This section starts from Kudurawa, a village on the southwest coast 38 miles south of Colombo, and crosses the Island in a northeasterly direction, passing just north of Adam's Peak to Rikilligaskada in the central part of the Island just south of Hanguranketa, from which point it turns to the east and thus maintaining a course at right angles to the strike, meets the coast at a point 33 miles south of the port of Batticaloa.

As will be seen the strata of the high massif in this line of section show a series of gentle undulations consisting of three synclines alternating with two anticlines. The most important of the synclines is that situated immediately to the east of Adam's Peak. This is eight miles wide and in its central portion the gneisses with their associated beds of quartzite and limestone lie nearly flat. In this syncline near Watagoda the Kotmala Oya has cut its valley. This is succeeded on the east by a low anticline very deeply eroded by a tributary of this stream. Ramboda is on the east side of this valley near the axis of the anticline. As seen from a point northwest of Ramboda on the road between Kandy and Nuwara Eliya this is one of the most striking valleys in Ceylon. The stream here runs on the axis of the low anticlinal fold, the rocks on either side rising in high precipices displaying the basset edges of a series of gneissic rocks which present a well-bedded appearance. These beds dip away from the valley on either side at angles of from 10° to 25°. In the bottom of the wide valley of the stream, low hills can be seen, erosion remnants which are being rapidly swept away by the torrents which rush through the valley during the periods of heavy tropical rains.

At Ramboda the valley bottom is 2,500 ft. above sea level, while the precipitous cliff on the east of the town culminates in elevations of 6,500, giving a section of 4,000 ft. cut through nearly horizontal strata.

Further east in the section a low syncline and anticline are followed by another syncline in the bottom of which the Matale limestone band is seen folded upon itself.

On the strike of the Ramboda anticline 6.5 miles to the southeast of the village of Ramboda and immediately north of Nuwara Eliya, is the summit of Pidurutalagala, the highest point in Ceylon. While this peak has not been examined by the writer it is practically certain from the attitude of the rocks on all sides of it that it is carved out of a very low anticlinal arch, the continuation of that which northwest of Ramboda is occupied by the deep valley referred to above.

Adam's Peak, on the other hand, is cut out of a series of gneissic strata which, according to J. F. Campbell (13), strike northwest with an east dip at an angle of 72 degrees.

## Minerals of Economic Value

It is a rather remarkable fact that no deposits of metallic sulphide ores have ever been discovered in Ceylon.

### *Iron Ore*

In former times all over Ceylon, or at least in all the districts of the central parts of the Island, the manufacture of iron and steel was carried on by the Singhalese. Heaps of slag marking the sites of ancient furnaces are met with in many places. Up to the year 1904 it was still carried out on a small scale near Balangoda but the industry is now extinct, not having been able to survive in competition with the cheaper iron and steel from Europe.

The ore, which was hematite or sometimes limonite, was obtained from shallow excavations in the lateritic soil arising from the superficial decay of the country rock and the iron was smelted from it in small furnaces of the type of the Catalan Forge. The process employed has been described by Coomaraswamy in an interesting paper (18). The industry is also described as early as 1681 by John Knox, who for some 19 years was held as a prisoner in Ceylon by the King of Kandy, in his most interesting book entitled "An Historical Relation of the Island of Ceylon" .

There is a deposit of titaniferous iron ore on the east coast, 40 miles north of Trincomalee, which is estimated to contain over five million tons, but which has not as yet been opened up (16).

### *Thorianite*

In 1903 W. D. Holland obtained from the Bambarabotuwa District a quantity of a heavy black mineral occurring in cubic crystals, which was analyzed by G. C. Blake at the Imperial Institute. It proved to be a new mineral consisting chiefly of oxides of thorium and uranium. The name thorianite was suggested for it by Professor Dunstan. Subsequent investigations by the Mineralogical Survey of Ceylon showed that the mineral occurred in many localities of that portion of the Island underlain by the crystalline rocks of the Archean. It was found in the alluvial deposits of the river valleys and in the beds of the present rivers. The thorianite in these deposits was derived, in several cases at least, from pegmatite veins in the country rock, through which veins it is irregularly distributed. These deposits attracted much attention as it was thought that they might be of economic value as sources of thorium, uranium and radium. In 1905, 179 cwt. was exported. These expectations however have not as yet been realized, as no large deposits of the mineral have been discovered. Should such be found at some future time this interesting mineral, as well as certain other of the rarer minerals which occur on the Island—monazite, thorite, fergusonite, etc.—may come to be of economic importance. 75 tons of monazite were exported from Ceylon in 1921 and 100 tons in 1922. (19-20, 32, 33).

*Mica*

Deposits of phlogopite are found associated with the crystalline limestones at a number of places and small amounts are exported nearly every year. The exports in recent years however have fallen off to almost negligible amounts.

*Salt*

Salt is made in Ceylon by evaporation of sea water in shallow basins or lagoons. The local production is nearly sufficient for the needs of the Island. There is a small import trade but no export.

*Graphite*

The occurrence of graphite in Ceylon has been known from very early times and the deposits are among the most important in the world. The mineral was not however mined and exported until the year 1824. The mining of graphite is now the largest and most important mineral industry on the Island. At one time—in the year 1909—no less than 770 graphite pits were being operated. Now the number is much less and the exports have fallen off considerably owing to the competition of graphite from Madagascar. The export in the year 1926 amounted to 11,624 tons.

The mineral occurs in many places disseminated through limestones or gneisses. In some cases however the graphite deposits constitute bed-like masses running parallel to the bedding or foliation of the rock. In other cases it occurs in the form of true fissure veins which cut across this bedding.

Short descriptions of various occurrences are given in the several Administration Reports of the Mineralogical Survey of Ceylon, to which reference has already been made, and more extended papers have been written by several persons who have made special studies of individual deposits (58, 70). That by Bastin (8) gives a summary and review of the whole subject.

The only deposit which the writer visited is that at Ragedera, situated towards the centre of the Island 78 miles from Colombo in a northerly direction. In the year 1826 when the graphite industry was in a depressed condition this deposit was producing most of the graphite exported from the Island. This occurrence is a most interesting one, the graphite filling a typical fissure vein having a maximum width of 3 ft. cutting an acid orthoclase gneiss holding many small pink garnets. The vein in many places shows a distinct banding parallel to the walls, the graphite adjacent to the latter having the form of fibres arranged at right angles to the walls, while the inner portion of the vein is filled with graphite having a foliated or platy character. The vein consists of almost pure graphite in which at one place was found a group of large pyroxene crystals highly altered and impregnated through and through with graphite, showing that the process of filling this Regedera vein was not a uniform and continuous one, but that it was one which in its earlier stages led to the deposition of certain silicates, apatite etc. and that the menstruum then changed in character, altering, decomposing and removing these original minerals, wholly or in part, and depositing graphite which is now the chief and essential constituent of the vein (4).

*Gems*

Ceylon has been celebrated for its gems from the earliest times and is still one of the great gem producing countries of the world.

These gems are found in alluvial deposits along the courses of the present rivers or of those of former times. The only gems which have been found in their original matrix are aquamarine, amethyst and moonstone.

The following precious and semi-precious stones are obtained in Ceylon: amethyst, aquamarine, chrysoberyl (and its varieties alexandrite and cat's eye), garnet (cinnamon stone), moonstone, peridot, ruby, sapphire, spinel, topaz, tourmaline, zircon.

While gems are found in many parts of the Island, the chief gem producing districts are those about Balangoda, Rakwana and Ratnapura. These are adjacent to one another and lie between the city of Kandy and the south shore of the Island. The name Ratnapura means the "City of Gems". The matrix of the aquamarines and moonstones is pegmatite or some allied rock, but they are found in the alluvial deposits as well. The former mineral is comparatively rare but moonstone is abundant and occurs in many places.

The gems are not found distributed everywhere throughout the alluvium but are concentrated in a layer of coarser gravel-like material which lies at the bottom of the alluvial deposits immediately upon the underlying bed rock, which is usually soft owing to partial decomposition. This coarser material is known to the Singhalese as "Illam". It must be reached by sinking through the overlying alluvium, generally to a depth of from 5 to 20 ft. When brought to the surface it is taken to the side of some pond or running stream and there washed in large cone-shaped baskets in essentially the same manner as that adopted in alluvial gold washing. In this way the mud and lighter stones are removed and the heavier pebbles including any gems that may be present settle to the bottom of the basket. This remaining material is carefully sorted by hand and any gems present recovered.

There are no companies or firms engaged in "gemming" on a large scale. All attempts in this direction have hitherto failed owing largely to lack of experience of the conditions ruling in the country, and more especially owing to the difficulty of securing a satisfactory title to any large areas of alluvial land, these generally being subdivided among peasant proprietors. The Singhalese who engage in this work take it up only at certain seasons, usually about November, May or June. Plate IX (a) presents a typical scene in one of the "gemming" areas, the long balanced bamboo pole with its bucket hanging from one end is used for baling out any water which may accumulate in the pit, or for hoisting the excavated material. As a general rule the owner or lessee of the land supplies the diggers with huts to live in, with their food, tobacco and tea free, or pays them their food equivalent in cash, and also gives them one half-share of the value of the gems after deducting the land share (one fifth) and 10% for what is called License Money.

To arrive at the value of the gems found, it is usual to offer them at public auction at which the gemmers are entitled to bid and buy in the gems if they are not satisfied with the prices bid by outsiders.

The value of the annual output of gems in Ceylon is stated by J. S. Coates, the Government Mineralogist, to be eight to nine lacks of rupees—that is to say, between $264,000 and $330,000. Occasionally the discovery of some large stones of exceptional value causes the value of the output to exceed this amount.

A more detailed account of the occurrence of these gems and the manner in which they are worked is given in another paper (1, 5).

Corundum, of the common opaque variety, has been found in the country rock of various parts of the Island, more especially in association with sillimanite. The same is true of the spinel.

The source of the sapphires, rubies, chrysoberyls, cat's eyes, and other valuable gems found in the "Illam" is as yet unknown. They undoubtedly derived from some rocks which form part of the crystalline complex on which the alluvium rests and from which they have been set free by the process of secular decay, but from which of these rocks is not as yet known, the country rock in the area where the gems are especially abundant being completely mantled by the residual clays.

The most valuable of the gems produced by Ceylon are the deep blue sapphires. Fragments have been found weighing from 200 carats up to 3.5 lbs. or 7,200 carats. These large masses however usually contain many flaws and imperfections. Fine specimens up to 100 carats in weight are not uncommon, though rarely without some defect in the nature of either flaws or "silk".

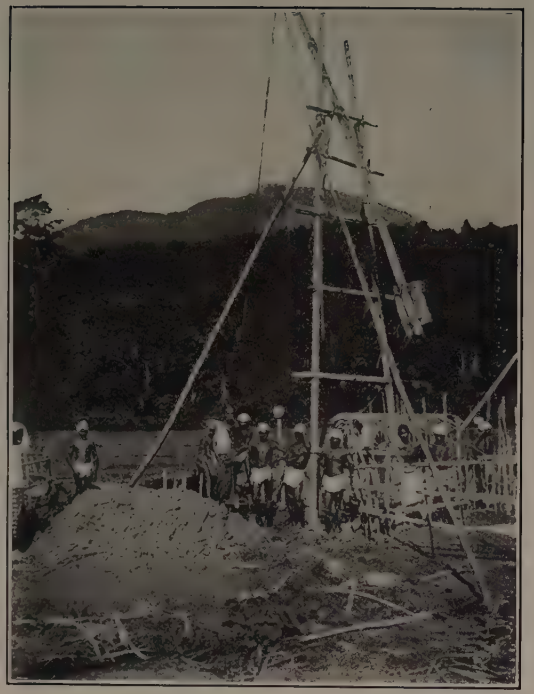
The finest blue sapphires were, till about 1906, found in the Rakwana district, but mining there was costly, owing to the Illam lying deep, and as the supply became scarcer the working gradually ceased.

Much attention has recently been directed to the gem finds at Pelmadulla, about 12 miles from Ratnapura in an easterly direction, where sapphires and other gems to a value of some nine lacks of rupees ($297,000) taken from one area of between three to four acres in extent in a paddy field. These included some very large fragments of excellent blue sapphire, one and two pounds in weight.

Really fine blue star sapphires with six distinct rays visible in open light are very rare, most of the stones are of a greyish color inclining to blue and with a star not so clearly seen.

Good chrysoberyl, including cat's eye and alexandrite, are chiefly found in the "Illam" about Ratnapura, Bamberaboluwa and Morawak Korale, alexandrite occurring chiefly at the latter place and about Weligama.

Zircon is very common in the gneisses of the crystalline area being seen in minute individuals in almost every thin section of these rocks. About Matara near the extreme south point of the Island, colorless zircons are found in the country rock in individuals sufficiently large to be cut as gems, being sold there under the name of "Matara diamonds" owing to their brilliancy due to the high refractive index of zircon. Zircons also occur abundantly in certain granite intrusions about Balangoda, forming what Coomaraswamy has called the "Balangoda Series".



(a) *Gem mining at Pelmadulla—Southern Ceylon.*

(b) *The lighthouse at Dondra Head—The extreme southerly point of Ceylon, and of Asia*

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# HETEROTYPIC PROPHASES IN THE ABSENCE OF CHROMOSOME PAIRING[1]

By Myrtle Chalmers Melburn[2]

## Abstract

The prophases of the heterotypic division in a wheat-rye hybrid, in which the chromosomes almost always fail to mate, are described and compared with those in the pure parents in which mating is normal. Up to the end of synizesis the events in the hybrid are in all essentials exactly the same as in the pure parents. Consequently the appearances presented in these stages can have no significance in relation to mating, because mating does not occur in the hybrid. The first striking differences in behavior occur in the stages between synizesis and second contraction when the spireme of the pure species forms loops, the sides of which approximate and twist about each other; in the hybrid spireme the loops are quite irregular. At diakinesis in the pure species three bivalents can be found connected, the mode of attachment being one which could result only from a telosynaptic arrangement of chromosomes.

The entire evidence obtained in this study of the wheat-rye hybrid and its parents is in accord with the theory that the spireme is composed of univalent chromosomes "in tandem", and that mating by the formation of loops begins in the post-synizetic period when chromosomes are relatively long and thin. This affords ample opportunity for cross-over phenomena.

## Introduction

Recent cytological work has shown that in certain types of plants the chromosomes fail to pair at the heterotypic division. Such plants should furnish new evidence in the study of the difficult problems connected with the mating of the chromosomes. The prophasic events in such plants studied in close comparison with those in normal plants should reveal significant differences. The omission of mating may be expected to cause departures from the normal prophasic appearances and thus render it possible to identify the exact stage at which mating occurs and to interpret the mode of mating. (It is a well-known fact that the vast amount of careful investigation of ordinary forms in which mating is normal has led to marked differences of opinion with respect to these two points, i.e., the time and the mode of mating).

There are three known plant types in which chromosomes fail to mate. One such group comprises hybrids between distinct species or genera; the wheat-rye hybrid of Kihara (10) and of Thompson (15) is a typical example. In more than 80% of its pollen mother-cells no mating at all occurs, and in the remainder only one, two or rarely three pairs are formed from the 28 single chromosomes. The prophases in this hybrid have been studied and compared with those in its parents. The results are given in the present paper.

Likewise mating does not occur in the group of the haploid mutants several of which have originated in experimental material. Regarding their haploid wheat plant Gaines and Aase (7) make the following statement:

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"The early prophases are marked by the usual events. Synizesis occurs and also second contraction. No sufficiently intensive study has yet been made of the interesting problems that, no doubt, are presented by the prophases to warrant discussion at this time. In the late prophases and in the metaphases of the first division there are 21 distinct unpaired chromosomes in each spore mother-cell of both anthers and ovules. Occasionally two or rarely more chromosomes pair or at least adhere end to end."

A haploid mutant in *Nicotiana Tabacum var. purpurea* has been cytologically studied by Chipman and Goodspeed (1), meiotic stages of the haploids being compared and contrasted with the corresponding stages in the diploid *purpurea*. In all essentials the two mutants show identical prophase stages up to and through synizesis (first contraction). The initial manoeuvres for mating in the diploid are post-synizetic, i.e., take place after the spireme has come out of first contraction.

In addition to the hybrids and haploid mutants, a few apparently normal diploid species fail to carry through the mating process. In *Oenothera biennis* and *Oenothera biennis sulfurea* (4), *Oenothera muricata* (3) and also *Oenothera pratincola* (11) the presence of homologues is established by their behavior at the first metaphase, although neither at that time nor at diakinesis do they show mating relationships. Nevertheless, in these species, prophase stages up to and through synizesis are in agreement with corresponding stages in species where there is mating.

## Materials and Methods

The hybrids between wheat and rye, which furnished this material in which mating fails to occur, were produced from a cross identical with that studied by Thompson (15). The wheat parent is a *vulgare* of chinese origin; it crosses readily with rye. The rye is a spring type known locally as Prolific. All the material used in this study was grown at the University of Saskatchewan during the summers of 1925, 1926, 1927 and 1928, and during the winter of 1928-1929. This appears to be the first time a cereal has been used in a prophase study.

Three fixing fluids were used, chrom-acetic, acetic-alcohol, and modified Bouin's solution. The latter proved by far the best for this prophase material when stamens only were to be fixed. However, the nature of the problem required first of all a very careful study of seriation, and for this preliminary work entire spikelets of the hybrid and both parents were fixed in acetic-alcohol. A wheat spikelet shows in cross section three flowers (nine anthers), and this stage-range is further extended by the fact that the four sacs of one anther frequently exhibit age differences. Again, cereal anthers being long and narrow, prove highly favorable material for study. Rye anthers especially excel in this respect, being 75 to 80 cells in length. Cells midway in an anther sac are older than those at either end.

Sections, 4-15 $\mu$ thick, were made of all stages both in the hybrid and in the pure species. All paraffin material was stained in iron-alum hæmatoxylin.

Smear preparations of anthers, killed, fixed in acetic-alcohol and stained with Belling's iron-aceto-carmine, were used for two special purposes; first, to determine whether the spireme spun out of the first contraction "knot" was a continuous filament—it is evident that the uncut cells only can afford reliable evidence on this point—and, second, to verify certain highly important findings regarding chromosome attachments in the diakinesis stage.

Although both parents were studied in conjunction with the hybrid it was thought best to show figures of the hybrid and one parent only, namely, rye. In all essentials the two parents show identical features at corresponding stages, but the low chromosome number of rye makes an accurate illustration much easier.

## Description of Meiotic Prophases

### 1. In the hybrid

Pollen mother-cells of the wheat parent are approximately one-third larger than those of the rye parent, and those of the hybrid are one-third larger than those of the wheat in spite of the fact that only 28 univalent chromosomes are present. Throughout all prophase stages the contents of the nuclear cavity in the hybrid appear to be less crowded than in the parents. Aside from these and other distinctions incidental to differences of cell size, the pre-synizetic stages are alike in the hybrid and its parent. The chief events are as follows:

*Pre-synizesis*

A definite nuclear membrane surrounding the reticulum is present lying close to the periphery of the cavity. Granules of various sizes lie in or upon most of the threads and are especially noticeable at the points of thread connections. The nucleolus is large and round in the well-formed, even reticulum and contains vacuoles which become plainly evident when the sections have been sufficiently freed from staining. Some parallelism of the threads can be observed, and this condition is just as conspicuous in the hybrid as in the pure species. Sections cut from 4 to 8$\mu$ in thickness are best for the study of detail in these early stages, and in any one such section, two, three or four cases of parallelism may often be seen (Plate I-6).

*Synizesis*

Synizesis (first contraction) involves the contraction of the reticulum and this necessitates a severance of its connection with the nuclear membrane in many places. The reticulum pulls away from approximately two-thirds of the surface and masses against the remaining one-third; during this period the nucleolus becomes more or less flattened against the membrane. Before separation actually begins, the reticulum displays characteristic changes in its net work. Near the periphery the threads become contracted and thickened, and the meshes become larger (Plate I-7). Threads at the center thicken conspicuously without the mesh increasing. Meshes soon disappear entirely in this central region and threads unite irregularly; no extended approximation of threads can be traced. Condensation proceeds until the characteristic

"knot" is formed; it is elongated rather than spherical. During this contraction process fine strands long continue to connect the main body of the reticulum with the nuclear membrane, and even at maximum synizesis some of these are still evident. Contraction apparently varies in degree but it is always of long duration; all the anthers of one flower are sometimes found in this stage.

Little can be said about the nature of events which take place within the "knot". The chromatin stains heavily and even thin sections reveal no more than the presence of an irregular, thick, closely crowded tangle of filament. Even after the "knot has begun to loosen, the filament appears thrown out in distinct, well-formed loops at one focal extreme, and in the closely massed condition at the other.

*Post-synizesis*

A continuous filament, the spireme, is spun out from the loosening knot. A special effort was made to establish the fact of its continuity. Smear preparations were used in order to get uncut nuclear contents, and in cells so examined no free ends were found in the spireme. Further, in paraffin sections, whenever free ends are seen they invariably come into view at the focal extremes. Such ends are evidently cut ends.

Loops are apparent as the spireme emerges, some close and some widespread. This spireme filament shows "doubleness" in some portions. In most preparations the phenomenon in each portion could be followed for a short length only, but there could be no doubt of its presence (Plate I, 8 and 9). This phenomenon of "doubleness" in the continuous spireme of the hybrid in which no mating occurs is a very significant feature.

The loosening out of the spireme occupies a much longer period of time than does the contraction of the reticulum to form the knot. Some bending and twisting of loops is seen but for the most part loop sides are well separated from each other, and it is possible to trace the spireme for a considerable length (Plate I-9). It is a marked feature of the hybrid that its spireme never succeeds in completely emerging from first contraction. When second contraction stage begins, there is still a portion of the synizetic knot in evidence (Plate I-10). This feature constitutes the first real difference in prophase behavior between the hybrid and the pure species and bears evidence of being a most important departure from the normal course of events. Its probable meaning will be discussed later.

*Second contraction to first metaphase*

As soon as the second contraction has definitely begun it can be seen that there are marked variations in the diameter of the filament. Condensation proceeds with a general thickening of the filament but certain irregularly alternating regions become attenuated and strained in appearance (Plate I-11). The loops which persist as contraction continues are the kind which would result from the pulling down of any long and continuous filament into a tight mass. Occasional breaks are seen in the filament at this stage showing that

some small amount of segmentation has already taken place (Plate I-11). The radiating loops become reduced in number but often one or two persist; frequently, in such an unabsorbed portion, the actual transformation of that part of the spireme into one or two univalents can be seen in progress (Plate I-12).

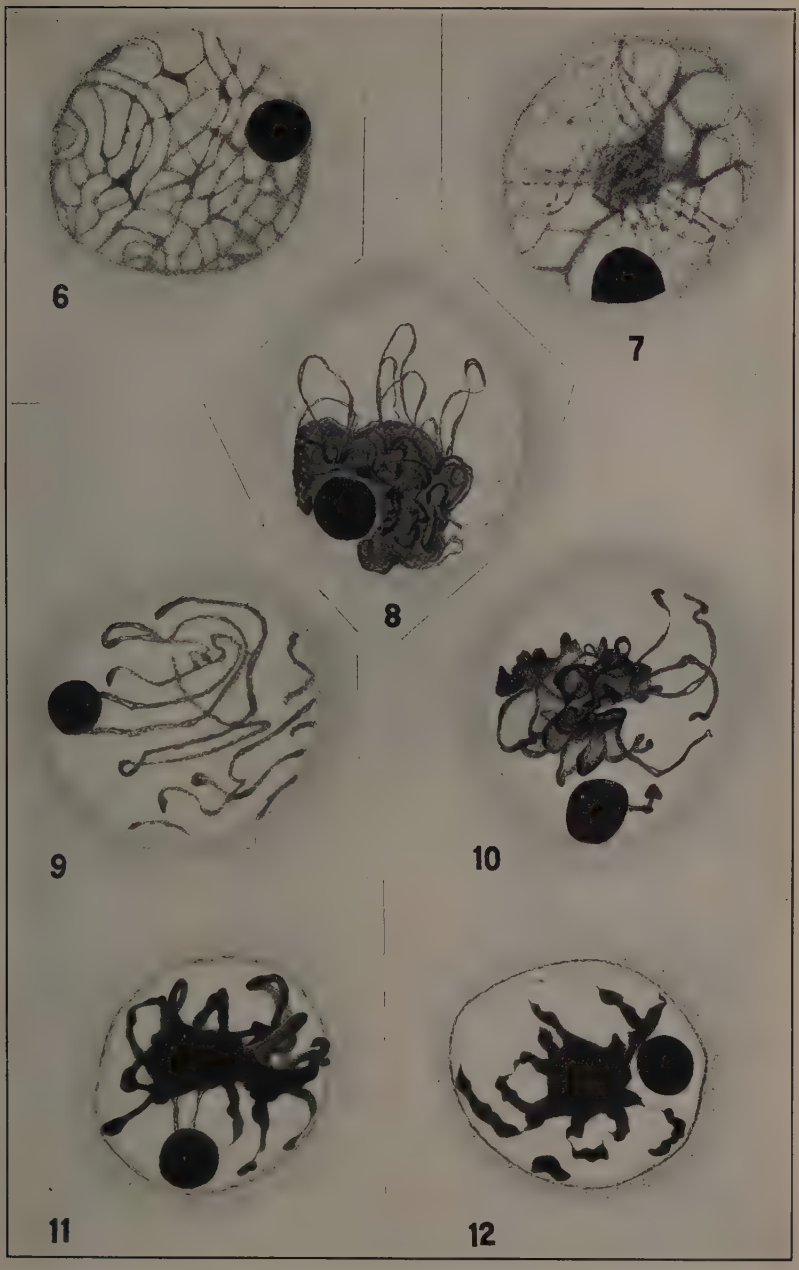
The density of this second contraction knot completely obscures what transpires within it. However, subsequent events show that a further condensation of the spireme into a shorter, thicker structure composed of chromosomes "in tandem" takes place. As the knot loosens some of the latter are cast out towards the periphery of the nuclear cavity. This state is therefore, comparable to that of "diakinesis" of normal meiosis, although relatively few chromosomes succeed in freeing themselves to move to the characteristic peripheral position (Plate II-13). These free univalents are soon pushed back to the central mass, thus consummating what many investigators call "third contraction" (Plate II-16). Simultaneously, come the dissolution of the nuclear membrane and the formation of the spindle fibers. No particular study was made of the origin of the spindle fibers but the disappearance of the nuclear membrane and the inception of the spindle are seemingly one event in point of time. While the membrane is present, the spindle fibers are not in evidence, and when the membrane is no longer visible the spindle fibers are already prominent. Mention may be made here of two frequently reported phenomena which are observed in connection with the spindle; the bipolar is often preceded by the multi-polar condition, and the crescent-shaped spindle is of very common occurrence (Plate II-19).

When the spindle is established, the massed chromosomes begin to draw out in a cluttered irregular fashion (Plate II-17) extending ultimately from pole to pole. The first division from this point and the second division have been completely described by Thompson (15).

As previously stated, one or two bivalents are sometimes formed and appear as loosely connected pairs at the metaphase (Plates II-18 and 19). However, all through the stages from spireme onward, the presence of this occasional

FIG. 1. *Portion of nuclear contents going into second contraction; one loop expressing loose mating.*
FIG. 2. *Maximum second contraction; pair attached to, but not included in, the knot.*
FIG. 4. *Similar pair found cut off in a separate section.*
FIG. 3 AND 5 *Show chains of four univalents found in mid metaphase.**

* *All text figures throughout the paper have been drawn according to the description given for Plate figures, except that figures 25, 27 and 28 are from smear preparations, hence their greater size.*

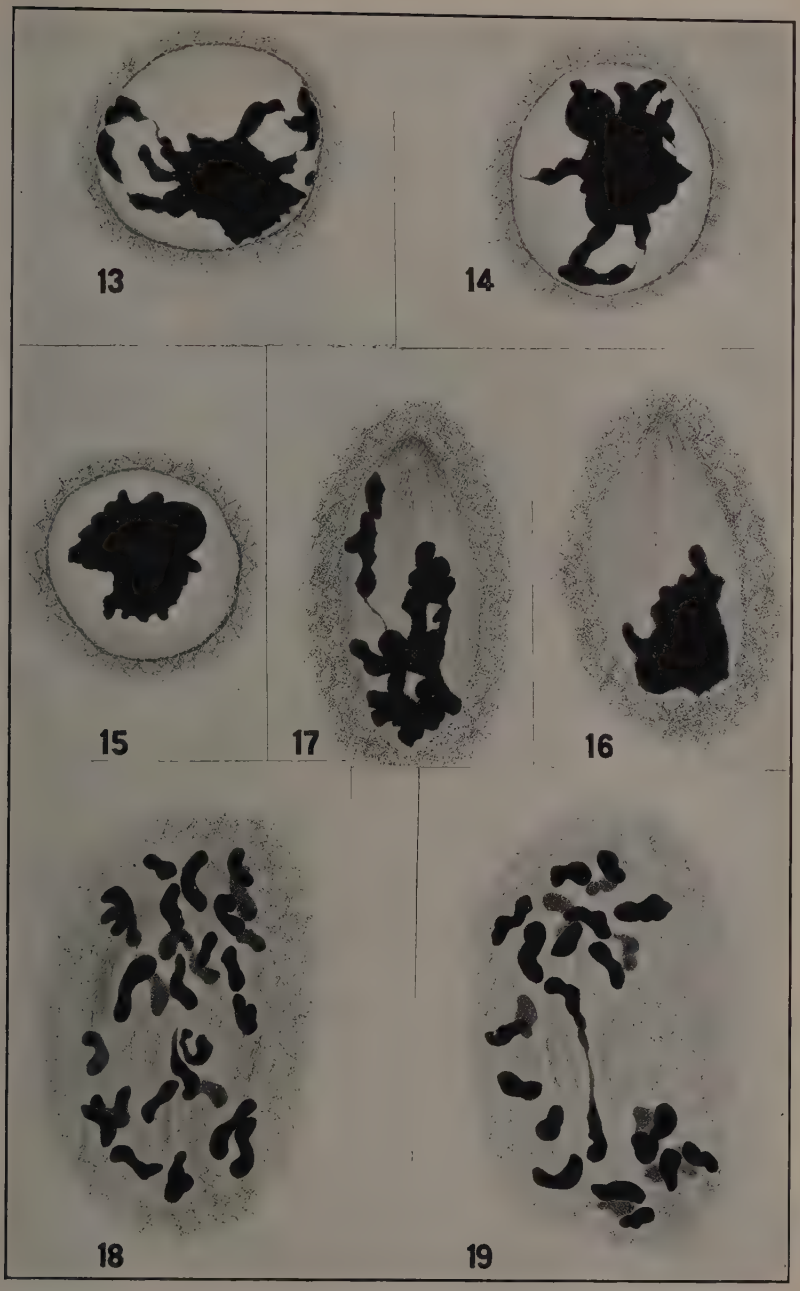



WHEAT-RYE HYBRID

FIG. 6. *Pre-synizetic reticulum showing some parallelism of threads.* FIG. 7. *The same just beginning to go into synizesis ("first contraction").* FIG. 8. *Synizesis. First few loops emerging. They show "doubleness".* FIG. 9. *Portions of spun-out spireme. "Doubleness" evident. Ends are cut ends.* FIG. 10. *Section of same cell showing portion of synizetic knot persisting.* FIG. 11. *Going into second contraction. Note irregular loops.* FIG. 12. *Somewhat later stage. Formation of univalents by constriction of spireme, i.e., chromosomes "in tandem".*

EXPLANATION OF PLATES

NOTE:—All plate figures are made from paraffin sections of pollen mother-cells killed and fixed in modified Bouin's solution, drawn with the aid of a camera lucida, Zeiss 2 mm apochromatic oil immersion objective and 25 × ocular. The magnification is ×3120 reduced 0.5 in reproduction to 1560.




WHEAT-RYE HYBRID

FIG. 13, 14 15. *Show varying degrees of second contraction.* FIG. 13 AND 14. *Constriction and condensation evident.* FIG. 16. *Third contraction. Spindle fibres prominent.* FIG. 17. *Chromosomes beginning to come out of third contraction.* FIG. 18. *Metaphase showing 28 univalents. Note some univalents are still connected by fine strands.* FIG. 19. *Metaphase. 26 univalents and one loosely connected bivalent pair. Crescent-shaped spindle.*

mating can be detected. It shows itself first in a closer conjunction of loop sides prior to and during the progress of the second contraction (Fig. 1). In maximum second contraction a bivalent pair is sometimes seen protruding from the knot (Fig. 2). Sometimes a pair is found in a section entirely cut off from the knot (Fig. 4). These rare matings are even more conspicuous at "diakinesis", when the presence of a detached pair makes a striking picture at the periphery. Often during the metaphase three chromosomes are seen attached "in tandem", and stretched lengthwise of a cell; even four or five can sometimes be found definitely connected in this fashion (Fig. 3 and 5).

### 2. In the rye parent

The similarity of pre-synizesis in the hybrid and its parents has already been emphasized, and the description given for the hybrid applies in all essentials to the same stage in the parents.

*Synizesis and post-synizesis*

The mid-synizetic knot absorbs the stain more densely than in the hybrid, but as similar differences in staining have been noticed among pure species of wheat it seems unnecessary to attach any significance thereto. The knot masses against one side of the nuclear cavity and the nucleolus is flattened at this stage. Thin sections reveal a knot similar in appearance to that seen in the hybrid. It is composed of a ball of tangled threads which gradually become fewer in number and greater in diameter. In reality it is probably not a case of numerous threads being present but rather numerous turns in the same threads. Throughout this stage, which persists longer than any other prophase stage, the spaces in the thread-tangle are occupied by an achromatic substance which gradually disappears toward the end of the phase.

When the filament begins to loosen out of this contracted knot, loops appear at the edge. In fact even at what appears to be maximum contraction, one or two such loops can often be found (Plate III-29). The spireme continues to be spun out in all directions, an undeniably continuous spireme. Hundreds of cells were examined in smear preparations and no free ends were seen. Ends found in paraffin material were evidently cut ends as described under the hybrid.

The spireme appears to be single, but a critical examination of a stretch of filament favorably placed and perfectly stained reveals its "doubleness" (Plate III-30 and 36). Although this "doubleness" cannot be readily detected in the majority of cells, its existence is unquestionable. The spireme continues to be looped back and forth through the nuclear cavity and a very considerable portion of its length can be traced successfully (Plate III-36). Very early in the process some of the loop sides become significantly close and even twisted about each other. The sorting out and definite re-arrangement of spireme regions into close loops with more or less parallel sides becomes more general as the spireme itself gradually increases in diameter and decreases in length (Plate III-31 to 35). It may be inferred, therefore, that adjacent portions of this spireme constitute homologous chromosomes "in tandem" i.e.,

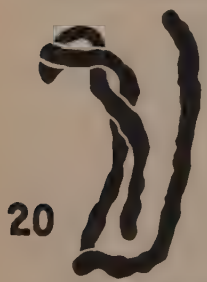
in telosynaptic relationship. Since the spireme is a continuous filament its entire 14 chromosomes are "in tandem". Not only is chromosome A attached end to end to its homologue $A_1$, and B likewise end to end to $B_1$, but one of the $AA_1$ pair is attached to one of the $BB_1$ pair end to end, and the $BB_1$ pair to the $CC_1$ pair and so on, forming a continuous chain of chromosomes.

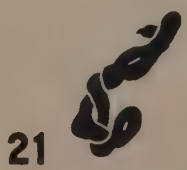
These loops are much too long to be accommodated on a radius of the nuclear cavity; even the diameter does not afford sufficient length in most cases at this early stage when the chromosomes are long and thin. The sides of a loop, therefore, can be seen extending across the cavity and they appear as though each of the parallel portions were a separate unit of spireme (Plate III-32). The next consecutive section of the same cell, however, often reveals the true relationship of the parts. At this stage, as shown in Plate III-34 the ends of the loops, having followed the curve of the nuclear cavity, were bent out of the plane of the section containing the parallel sides of the same loops.

Characteristic pairs can readily be recognized at this stage and later. One such pair is shown in Fig. 20. There is also some evidence to show that the same pair is frequently first to emerge from the synizetic knot. Formation of the full complement of loops is by no means simultaneous; conjunction of loop sides can have proceeded appreciably for some pairs, while others have not yet been arranged. The length of the spireme and the relatively small space in which it performs its manoeuvres necessitate this. Moreover, those parts which come out of the "knot" first would naturally be expected to be the first to begin mating movements.

*Second Contraction*

It is difficult to describe the exact point at which the second contraction begins. As soon as the spireme is completely spun out, it begins to increase in diameter, and the earliest loops as soon as definitely arranged, proceed to contract while the spireme of the earliest loops thicken. In Plate IV-38 four obvious cases of advanced mating in loop stage are shown. In the lower right portion of the cavity twisting and condensation have proceeded so far as totally to obscure the space between the loop sides; in the same section regions of spireme can be seen which have not yet succeeded in mating. In one of the



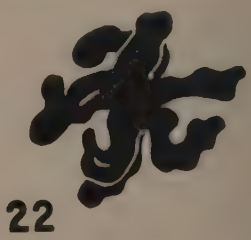
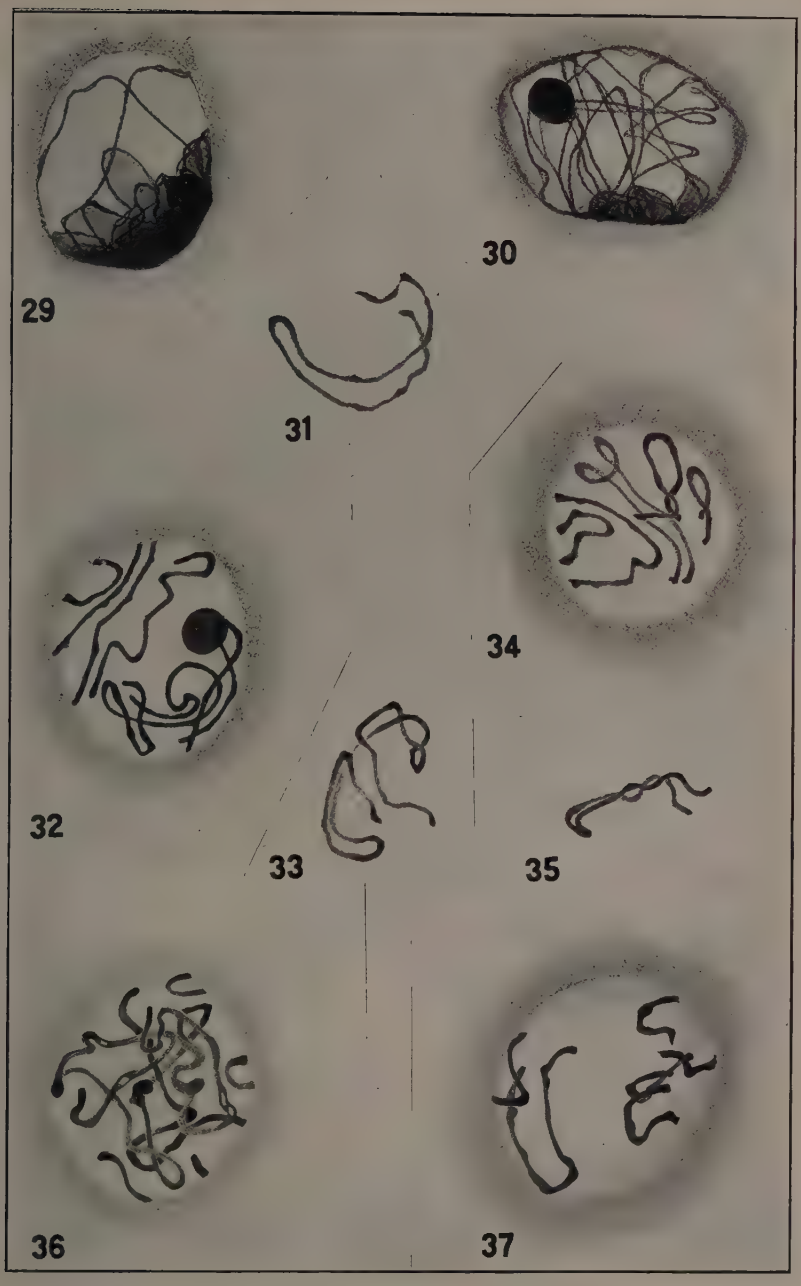




FIG. 20. *Characteristic loop composed of two univalents mating. A portion of contiguous unmated spireme length is shown.*
FIG. 21. *A tightly twisted loop. Note the continuity of spireme evident at the lower end.*
FIG. 22. *Maximum second contraction; seven loops can be counted.*




RYE

FIG. 29. *Synizesis. First few loops emerging. Spireme shows "doubleness".* FIG. 30. *Spireme almost all out of synizetic knot.* FIG. 31–37 *(inclusive.) Spireme stage.* FIG. 31. *A characteristic loop which lies curved close to the nuclear membrane.* FIG. 32, 33 AND 34 *show loops whose sides are more or less parallel. Several loop-ends are in evidence. The sides (or arms) of a loop are frequently found in one section and the loop-end in the next section.* FIG. 35. *Two significant loops well established.* FIG. 36. *Most of the spireme length shown in this figure is continuous. Free ends are cut ends. At four places in the filament "doubleness" is evident.* FIG. 37. *A tangential section in which loop-ends only were found.*

latter regions "doubleness" is noticeable, and in the same figure the tips of two loops clearly illustrate the process of anastomosis. The mating of a pair may be considered as consummated when the approximation of its loop sides has reached its maximum for that pair. Each loop is, therefore, composed of two homologous chromosomes, and segmentation of the entire loop from the rest of the spireme sets free one bivalent pair. Some pairs undergo segmentation much earlier than others; occasionally a tightly twisted pair cut off in a section separate from the rest can be found as shown in Fig. 21 and in Plate III-35. Probably such a pair would not be involved in a second contraction knot but would at once move out to the periphery. The knot at maximum second contraction is not usually so dense as to obscure the seven bivalents (Fig. 22 and Plate IV-39). The degree of contraction, for some undetermined reason, varies considerably.

*Diakinesis to Metaphase*

When second contraction is complete the bivalents begin to separate and move out to the characteristic peripheral position. This proved one of the most interesting and fruitful stages for study in the pure species, as it had in the hybrid.

Some of the paired chromosomes are still quite long at this stage and a pair may show one, two or three twists, or none at all (Plate IV-40). One end of the pair is almost always well rounded while the tips of its univalent members at the other end are more or less free from each other and possess fine trailing terminal strands shown in Fig. 25 to 28. The well rounded end is the distal or peripheral end of the loop, while the ragged tips at the other end are the points at which the loop segmented free from the spireme (Fig. 28 and Plate IV-40, 41).

It is very easy in early "diakinesis" to find two bivalent chromosomes still attached, and this attachment is always of the same character, namely, by one univalent end in each (Fig. 26). Cases of three bivalents still attached can be found also, although they are not common, 15 instances being found in the course of a search of several hundred cells (Fig. 25, 27, 28 and Plate IV-41). The mode of these attachments is significant. A portion of the spireme containing three loops which represent three bivalents in the making is illustrated in Fig. 23. The point where the two homologues are united end to end is marked "X"; the point where two non-homologous chromosomes are connected end to end is marked "O". In Fig. 24 the same portion of the spireme is shown after each loop has made one twist. Considering the middle bivalent, it is obvious that the tips of its two univalent components at "O" and "O" will be strained in different directions when completing the separation from the other two components. This is exactly the condition shown in Fig. 25, 27, 28 and in Plate IV-41. Obviously this mode of connection uniting three bivalents can result only from a telosynaptic arrangement of homologous chromosomes.

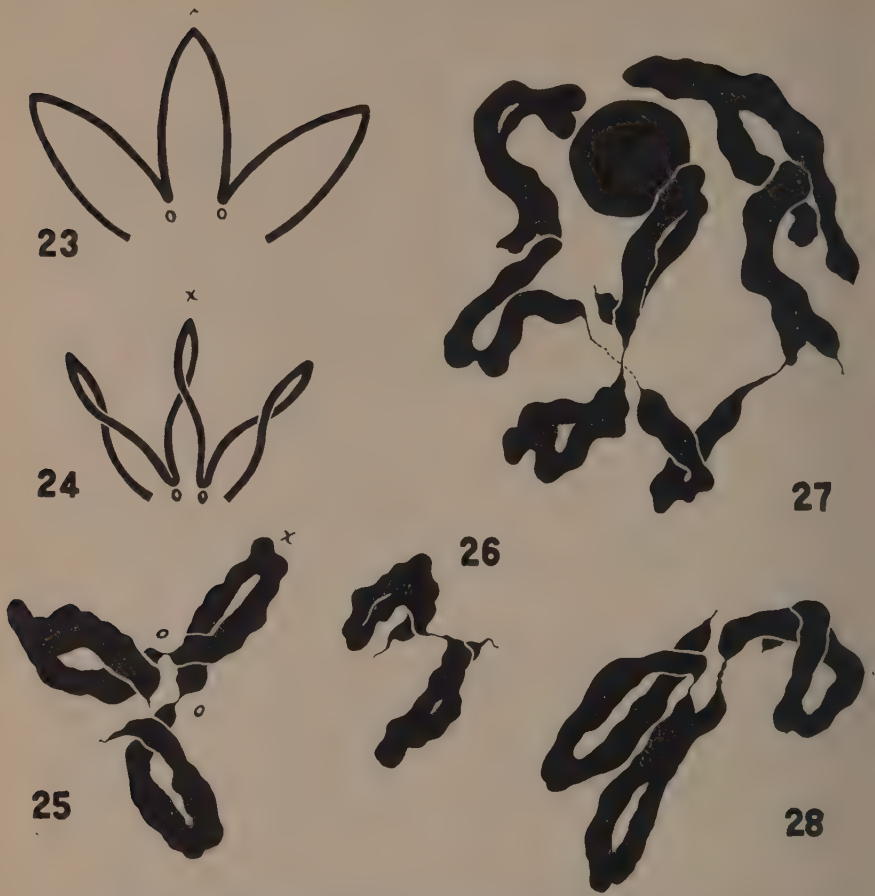
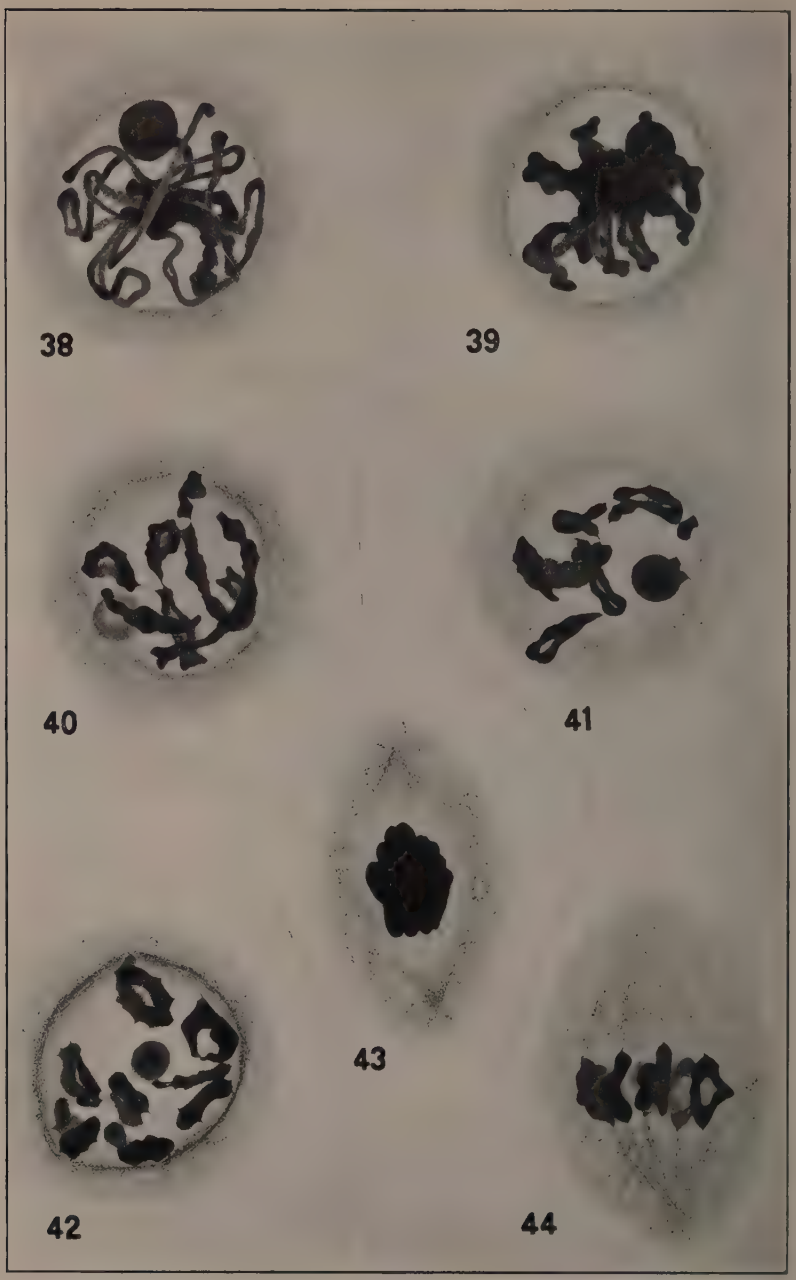



FIG. 23. *Diagram indicating a portion of spireme composed of three loops which represent three bivalents in the making. Full explanation given in the text.*
FIG. 24. *The same after each loop has made one twist.*
FIG. 25 AND 28. *At diakinesis three bivalents attached. This mode of connection could result only from a telosynaptic arrangement of homologous chromosomes.*
FIG. 26. *Two bivalents attached at same stage. Note free univalent end in each bivalent indicating direction of recently severed attachments.*
FIG. 27. *The full chromosome set at diakinesis. One connecting strand shown by a dotted line so as to indicate the fact that it was at a different focus.*

During the progress of diakinesis these connections are broken, bivalent chromosomes become shorter and thicker and the two component members of each of the latter generally assume less intimate contact with each other. The seven bivalents differ in this respect, forming rings or crosses, lying rod-like side by side, or retaining one or more twists. A connection with the nucleolus is retained, one pair being always attached to it (Plate IV-41, 42). The nucleolus becomes much paler and, by the time the chromosomes have moved from their peripheral position and massed into "third contraction"




RYE

FIG. 38. *Second contraction. Five loops (five bivalents) still evident. In one twisted bivalent (lower-right) loop-sides are obscured. A portion of the spireme is still unmated. In one place "doubleness" is evident. In two loops anastomosis is seen completing conjunction.* FIG. 39. *Maximum second contraction. Seven bivalents can be counted.* FIG. 40, 41, and 42 *are of stages in diakinesis.* FIG. 40. *Seven bivalents. Connection in two cases is by univalent ends only. In some pairs the two componeni members are still in intimate contact.* FIG. 41. *Three bivalents still attached. This mode of attachment could result only from a telosynaptic arrangement of chromosomes.* FIG. 42. *Late diakinesis. The two components of each bivalent pair are much less intimately in contact.* FIG. 43. *Third contraction.* FIG. 44. *Metaphase. Seven bivalents on the equatorial plate.*

knot, it has disappeared entirely. In the meantime the nuclear membrane after becoming wide and "felt-like" in appearance has given place to spindle fibres as described in the case of the hybrid. The third contraction (Plate IV-43) is of short duration and soon loosens into the characteristic regularity of the metaphase plate shown in Plate IV-44. The chromosomes possess at this stage a quite definite shape and smooth outline.

## Summarized Comparison of Prophase Behavior in Hybrid and Parent

1. In a wheat-rye hybrid and its parents, pre-synizetic stages are found to be alike except in points attendant upon differences of cell size. Some parallelism of threads is evident in the contracting reticulum in each, and some coalescence of threads occurs as the reticulum becomes of larger mesh in the course of synizesis.

2. In hybrid and parents alike, the spireme filament which emerges from the synizetic knot shows some "doubleness". It is reasonable to suppose that there is a common cause for this identical phenomenon. Whatever may be its significance it cannot mean parasynaptic mating since a study of subsequent stages has proved that the chromosomes of the hybrid usually fail to achieve mating.

3. The spireme is certainly continuous in the pure species and seems to be so in the hybrid.

4. (*a*) In the pure species mating manoeuvres begin quite early in the spireme stage, by the formation of loops. Each loop comprises two homologous chromosomes united at the apex of the loop. Individuality is expressed in varying degrees of approximation of loop sides; some loops anastomose while most of them twist more or less.

(*b*) This kind of loop formation is very infrequently detected in the hybrid and its appearance in small amount is accounted for by the fact that no mating occurs in approximately 85% of the cells, while mating, which is loose in the other 15% occurs only in the case of one, two or three pairs of chromosomes.

(*c*) The hybrid spireme enters the second contraction stage without having entirely emerged from the first contraction knot; this is interpreted as signifying an early recognition of the absence of mates and the consequent futility of prolonging the spireme stage.

5. (*a*) In the parent species the loop mates can be plainly distinguished entering the second contraction stage. The degree of contraction varies and some segmentation of early mates occurs before the maximum point of the phase is reached; a few of the pairs exhibit two, three or four twists.

(b) The hybrid spireme is drawn down into second contraction in irregular loops, the sides of which show little or no affinity for each other and do not evince twisting.

(6). (*a*) Out of second contraction in the pure species typical bivalents are released. The resultant stage is known as "diakinesis". Frequently, two bivalents are still attached in a characteristic fashion but three bivalents more rarely retain these connections. The particular mode of attachment is possible only as a consequence of a telosynaptic arrangement of homologues.

(*b*) Usually a few univalents only are cast out to the periphery in that stage which in the hybrid corresponds to "diakinesis" but a bivalent does appear occasionally. Such a free pair always appears well rounded at one end, but at the other end it displays free tips crossed over.

7. The third contraction is normal.

8. (*a*) In the case of the pure species the third contraction knot loosens out into a symmetrical metaphase plate of bivalents.

(*b*) But at the conclusion of the third contraction the chromosomes of the hybrid emerge sprawling out to spread from pole to pole. Occasional pairs can be seen loosely attached at one end, and sometimes univalents adhere end to end in chains of three or four.

## Discussion

The immense volume of literature on the mating of the chromosomes has been so well reviewed by many authors that there is no need to add thereto. Neither is it necessary to attempt an exhaustive argument regarding the rival parasynaptic and telosynaptic conceptions to which previous work has led. The purpose of the present investigation has been to examine evidence of a type different from that obtained from the usual sources. The bearing of this evidence on the two conceptions of synapsis is, therefore, all that requires discussion.

According to the theory of parasynapsis the chromosomes begin mating in a side by side position prior to synizesis and complete the process before emerging from the synizetic knot, so that the emerging spireme is already bivalent. According to the telosynaptic conception the chromosomes are arranged end to end in the spireme; mating takes place through a looping process which begins subsequent to synizesis and is completed during the second contraction.

Practically all observers report the occurrence of some parallelism of threads in the early stages (i.e., pre-synizesis )but its occurrence is interpreted in three different ways. Upholders of the parasynaptic theory see in this phenomenon the side by side mating of chromosomes. For most proponents of the telosynaptic view it means the re-association of the two halves of chromosomes split during some earlier stage. Cleland (4) claims that the frequency with which cases of parallelism appear is no more than should be expected from the presence of numerous threads in such an involved relationship. Denham (5) also thinks that much of the apparent parallelism may be due to a superposition of strands lying at different depths.

From the detailed description given above it will be seen that the pre-synizetic and synizetic stages in the wheat-rye hybrid and its parents are found to be alike in all essentials. It seems reasonable, therefore, to conclude that no significance can be assigned to thread manoeuvres at this early stage in respect to their bearing on mating. The association of threads in a hybrid whose chromosomes do not mate, obviously cannot be interpreted as a parasynaptic union, and there is no justification for a different interpretation of an identical appearance at the same stage of meiosis in the parent species.

Chipman and Goodspeed (1) report on the Nicotiana haploid as follows: "Just as in the diploid, it was not possible to find any evidence of the longitudinal split or a paired condition in the pre-synizesis spireme".

The spireme emerging from synizesis is found by some to be a closed single filament. Others find it exhibiting duality or "doubleness". However, the majority of observers do report such a "doubleness" in the spireme at this stage. According to adherents to the parasynaptic view this condition remains evident throughout later stages. Most supporters of the telosynaptic theory who report duality find that the split soon closes so that the spireme proceeds to and through the second contraction as a single filament. On the other hand the phenomenon is found by Digby (6) to persist from the earliest through the latest prophase stages, and by Denham (5) to be not so conspicuous but of just as long duration.

Other investigators notably Cleland (4), Gates and Rees (8) and Kulkarni (11), although they find telosynaptic arrangement of homologues in their material, fail to observe any "doubleness" in the post-synizetic spireme. Cleland reports it totally absent in *Oenothera muricata* (3). Considerable importance has been attached to this singleness of the spireme filament as being strong evidence that no mating has taken place up to that point of meiosis.

The spireme in the haploid tobacco is found by Chipman and Goodspeed (1) to be a single filament; but it is likewise a single filament in the diploid plant. The authors refer to the latter as "highly filamentous" and "strictly single, uniform and smooth". The value of this evidence lies in the fact that the spiremes in haploid and diploid purpurea are alike.

So, too, the wheat-rye hybrid and its parents have like spiremes, but their similarity lies in their "doubleness". Since the latter phenomenon is a feature of both hybrid and parent, its meaning, whatever it may be, can have nothing to do with mating. "Doubleness" of the spireme is more easily demonstrated in the hybrid than in the pure species; it is especially prominent in the later, thicker stages of the filament before and during the second contraction. Cleland records this phenomenon towards the end of the second contraction in *Oenothera franciscana* (2) and interprets it as a premature splitting for homotypic division; this interpretation is quite in accord with heterotypic events in the hybrid (15).

The continuity of the spireme is now very generally admitted. The spireme is a continuous filament in the *Oenothera* species (3, 4, 11). It is continuous in the haploid tobacco and also in the corresponding diploid prior to mating.

However, in their diploid Chipman and Goodspeed (1) find that pairing begins in early post-synizesis and they observe free ends at the same stage, which would seem to mean that segmentation and pairing are simultaneous. It may be pointed out, however, that the drawings used by the authors to illustrate this stage are stated to have been made from very thin sections and it is just possible that loop ends belonging to, and connecting the parallel mating portions would be found in consecutive sections of the same cell. Due to this reported occurrence of so early a segmentation of the spireme in diploid *purpurea* this species and its haploid can enter into this discussion no further.

Special efforts were made in the present study to determine spireme continuity. It is certainly continuous in the pure species. The point cannot be settled so definitely, however, for the hybrid spireme since it does not emerge completely from the first contraction stage before the onset of second contraction. But, no free ends could be observed in smear preparations where uncut cells were present.

At this point a tentative explanation may be offered for the failure of the hybrid to achieve a complete emergence from the synizetic knot before the second contraction stage begins. In the pure species the spireme stage is of long duration; it is the period when mating begins and gets well under way. But, since little or no mating occurs in the hybrid, it is unnecessary for the spireme stage to last so long. It is noteworthy that the spireme of *Oenothera biennis* (4) also, fails to emerge completely from the first contraction knot.

There are considerable differences of opinion regarding the parallelism of portions of a spireme filling the nuclear cavity. It is thought by some investigators that the apparent parallelism is of no more frequent occurrence than can be expected from the numerous turns in the filament and that it is due to chance. Those who attribute a significance to the parallelism belong to the two groups supporting the parasynaptic theory and the telosynaptic theory. The first see in these parallel portions the slightly separated mates (longitudinal halves of the spireme) which paired in pre-synizesis. The others consider them to be the parallel sides of a loop at the apex of which homologous chromosomes are united. The events described in this paper for the pure species support the latter interpretation.

Looping is a generally recognized feature of this latter part of the spireme stage and some investigators, as Gates and Rees (8), and Latter (12), count and figure a definite number of loops identical with the haploid chromosome number. Loops occur in the spireme of the wheat-rye hybrid also, but they have no significance since the sides do not approach each other nor do they anastomose and twist as in the pure species. Moreover, seven loops can be counted during the second contraction in the rye parent. Cleland reports the presence of radiating loops which, as the second contraction progresses, become closely appressed, but he observes no twists. Neither does Kulkarni (11) who writes as follows: "As the loops become shorter and shorter, their two sides approach until in some cases they actually come to lie against each other".

In the two cases just mentioned homologous chromosomes have been proved to be telosynaptically arranged, although they fail to mate.

It seems significant that this failure to mate is associated with lack of twisting in the loop stage. Some of the early twisting of loops in pure species may possibly be due to the crowded condition of the fully spun-out spireme as contrasted with those of the wheat-rye hybrid and *Oenothera biennis* and *Oenothera biennis sulfurea;* the spireme in these fails to emerge completely from the synizetic knot before beginning to go into second contraction. Whatever the cause or causes may be there are in the wheat-rye hybrid and in the two *Oenothera* species mentioned, three similar conditions, namely, incomplete spireme emergence, lack of loop twisting, and absence of mating. It is possible that the third condition explains the first two, i.e., absence of congenial mates. In the wheat-rye hybrid the presence of homologous chromosomes is constitutionally impossible. In the *Oenothera* species mentioned the events of the first anaphase prove that homologues are present but lacking in that degree of compatibility necessary to have achieved mating. Cleland (4) says of these *Oenothera*, "The failure of homologous chromosomes to pair is due to lack of affinity . . . . the results of divergence in their constitution".

The cytology of these *Oenothera* species shows that, although homologues are present they do not indicate their presence until they arrange themselves at the metaphase and proceed to disjoin. The present comparative study of a hybrid and its parents seems to show that homologues in a pure species display obvious mating relationships not only in the metaphase, diakinesis and second contraction, but also in the parallelism and twisting of loop sides prior to the second contraction.

In accounting for the occasional mating which occurs in the wheat-rye hybrid, Thompson (15) observes that "random mating amongst duplicated chromosomes does not occur normally, but may occur abnormally"; he expresses the opinion that these infrequent pairs are probably composed of wheat chromosomes, since duplicated wheat chromosomes are likely to have much more in common than those from wheat and rye (two different genera). This view is supported by the fact that a greater number of chromosomes—three or even four—have sometimes been found adhering end to end in the very early metaphase of this hybrid. The fact that chromosomes similarly connected at a similar stage are reported for the haploid wheat mutant (7) supplies additional evidence for this view. Further, two bivalents and one univalent have been found attached in one long piece in the metaphase of a wheat-ægilops hybrid (9). This seems to be a clear case of five univalent chromosomes attached "in tandem", four of which constitute two adhering pairs of loosely attached bivalents.

If the evidence adduced in this paper be assumed to prove that chromosomes are connected end to end in the wheat-rye hybrid, in the spireme stage and onward, it seems reasonable to suppose that "duplicates" would be adjacent therein, and that they would be the last to effect segmentation from each other.

One of the chief objections to the general acceptance of the telosynaptic theory has rested upon what has been considered its failure to demonstrate a physical basis for crossing-over. The objection is met, however, if telosynaptically arranged chromosomes begin mating by forming loops in the mid-postsynizetic period as held by Digby (6), Denham (5), Gates and Rees (8), Mottier (14), and others, because, at that stage, chromosomes are still relatively long and of correspondingly small diameter. To provide opportunity for the amount of crossing-over known to take place in any specific case it is not necessary for chromosome mates to be in intimate contact throughout their entire length. Such a contact combined with twisting movements would probably be conducive to a percentage of crossing-over far too high to be in keeping with genetical data. Drawings made to illustrate such contact and twisting of mating chromosomes prior to synizesis usually depict several points at which the members pass alternately above and below each other. From this complicated relationship ultimate disjunction would probably be accompanied by much more crossing-over than is commonly the case. Morgan (13) reports the amount of crossing-over in a sex-linked group of genes in Drosophila. According to him, there is no interchange at all for that chromosome pair in 43.5% of the eggs; one interchange in 43% of the eggs; two interchanges in 13% of the eggs; three interchanges in 0.5% of the eggs. This particular pair of chromosomes would, therefore, never need to be in contact at more than three points and that in only 0.5% of the eggs. The twisting of loop sides (i.e., a pair of mating univalents) immediately preceding the second contraction and the more intimate approximation brought about at maximum second contraction, followed by a partial withdrawal from so intimate a contact during diakinesis affords all the necessary opportunity for exchange of chromatin. In rye several twists are observed in the early loops but in late diakinesis it is usual to see one twist or none, rarely two and very seldon three.

## Acknowledgment

This investigation was initiated by Dr. W. P. Thompson and carried on under his direction. His assistance and encouragement are gratefully acknowledged by the author.

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# CHEMICAL AND PHYSICO-CHEMICAL CHANGES INDUCED IN WHEAT AND WHEAT PRODUCTS BY ELEVATED TEMPERATURES—I

By W. F. Geddes[2]

## Abstract

Heat treatments of wheat and wheat products were conducted in an apparatus which made it possible to study independently the influence of time, temperature and moisture content. Straight-grade flour, milled from Western Canadian hard red spring wheat (allowed a limited amount of aging) heat treated for varying times at different temperatures and normal moisture content (13.90%) was used in most of the studies. Baking tests conducted on this flour revealed progressive improvement in baking quality, as determined without bromate, with temperature or time of heating being extended within a certain range. No well defined "region" of improvement was observed. Improvement in baking quality was reflected in a better handling quality of the dough and, in the baked loaf, by a decrease in underfermented characteristics, and by a marked improvement in crumb texture. No significant alteration in loaf volume was observed. Improvement in baking quality induced by heat was not comparable in magnitude to that obtained by the addition of 0.001% potassium bromate to the baking formula, but induced the same general characteristics in the finished loaf. Baking tests with bromate on heated flour revealed damage to baking quality for all heat treatments. Extension of time or temperature of heating, above the range where improvement was observed, caused pronounced damage to baking quality as determined with or without bromate. The damage caused was reflected in decreased loaf volume, over-fermentation characteristics, and coarse texture. Within the range of damage, the baking quality was found to be approximately a linear function of the temperature for constant time of heating. Heat treatment resulted in a marked decrease in fermentation tolerance. This decrease could not be ascribed to lower diastatic activity, since baking tests after the addition of diastatic malt to the baking formula gave similar results. Increasing the moisture content at which heat treatments were conducted markedly reduced the temperature to which flour could be heated without damage to the baking quality. The safe temperature limit for various moisture contents has been fairly well defined. The limiting moisture content at which damage occurred for a fixed temperature and time of heating was very sharp. Heat treatment of wheats showed somewhat less damage to baking quality of the flour milled therefrom than heat treatment of flour under similar conditions.

## General Introduction

The twentieth century has witnessed efforts in various directions towards improvement in the quality of flour and of products manufactured from it. The plant breeder has contributed to these efforts by producing improved varieties of bread wheats, the milling engineer and the baker by developing more modern machinery, and more refined milling and baking processes. In this search for improvement the chemist has played his part by investigating the physico-chemical and chemical properties of wheat flour which are responsible for good baking quality or "flour strength". (The classical definition of "flour strength" is the ability of a flour to produce large well-piled loaves (16, 17).

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*Contribution from the laboratories of the University of Manitoba, Winnipeg, Canada, with financial assistance from the National Research Council of Canada. The present paper is the first of a series and is being issued as Paper No. 6 of The Associate Committee on Grain Research. It represents part of a thesis presented in partial fulfilment of the requirements for the degree of Ph.D. at the University of Minnesota.*

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In this connection, the influence of heat on wheat and flour has recently attracted the attention of investigators. This interest has centered along two lines—first, the possibility of an improvement in baking quality by proper heat treatment of wheat or flour, and secondly, problems arising from the necessity of artificially drying wheats, which carry excessive amounts of water for safe storage, by means of heat.

Previous to the last three years, there was comparatively little published information on the influence of heat on the properties of wheat and flour. Graham (13) observed that damp wheat might be dried in a kiln at 140° F. (60° C.), but Jago and Jago (18) stated that the gluten in wheat might be destroyed and the wheat thus rendered useless. Jago and Jago observed that gentle artificial drying of flour increased its water absorbing capacity to some extent and stated that drying of damp wheats would likely produce a similar effect.

In a study of the drying of wheat for milling purposes, Cox (11) found that drying wheat containing 16.3% moisture for one hour at approximately 140°F. (60°C.), reduced its moisture content to 12.9% and that the milling and baking qualities of the flour milled therefrom were not impaired. Cox confirmed this by another series of tests in which three lots of wheat were artificially dried at an average air temperature of 140° F. (60° C.). The temperature of the wheat, determined by withdrawing samples from the drier during the drying process, was found to vary between 110°F. (43.3° C.) and 132° F. (55.6° C.) with an average of 125° F. (51.7° C.).

Birchard (3) studied the influence of artificial drying of wheats at elevated temperatures on the baking quality of the flour milled from them. When small samples were dried in an air oven at 149° F. (65° C.) for two hours, no damage to the wheat resulted as evidenced by comparative baking tests on flour milled from the damp and the dried grain. Studies conducted on drying wheats of varying moisture content at different temperatures for three hours indicated that the safe temperature limit for drying was related to the moisture content present. With wheat containing 14% moisture the limit was approximately 176° F. (80° C.) and with 17% moisture, it was 158° F. (70° C.).

More recently, Kent-Jones (19) reported the results of an extensive series of investigations on the effect of heating wheat and flour on various properties related to strength. Reference will be made later to the detailed observations presented by this investigator, consequently only a brief outline will be given at this point. Preliminary experiments showed that heat treatment of wheat or flour under certain conditions resulted in a marked improvement in baking quality. As a result of further experiments, Kent-Jones (19) presented a graph (reproduced in Plate I) which showed the relationship between the time and temperature of heating a certain commercial flour and its baking quality. It will be observed from the graph that the higher the temperature to which the flour was exposed, the shorter the time necessary to secure an improvement in quality or, on the other hand, to "ruin" the flour. Thus to secure marked improvement in baking quality (represented by the deeply shaded

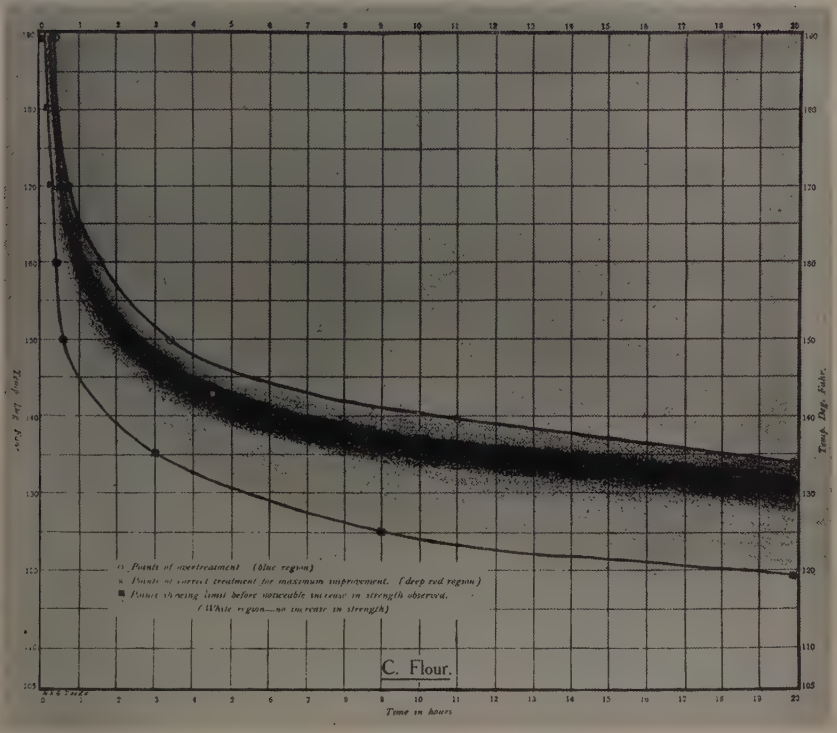
region, i.e., "deep red region"), it was found necessary to heat the flour for 20 hours at a temperature of 130° F. (54.4° C.), 11 hours at 135° F. (57.2° C.), six hours at 140° F. (60.0° C.) or two hours at 150° F. (65.6° C.). Heating the flour for the above mentioned times at respective temperatures approximately 5° F. (2.8° C.) higher than those specified resulted in decreased baking quality, (represented by the lightly shaded region, i.e., "blue region"), while at temperatures approximately 10° F. (5.6° C.) lower no improvement was produced (represented by the unshaded region, i.e., "white region"). In these studies the flour was heated with a moderate "natural moisture content", but the percentage moisture was not given.

Investigating the influence of moisture content, Kent-Jones (20) presented data which showed that with the time fixed, the higher the moisture content, the lower the temperature required for "proper heat treatment". Furthermore, it was claimed that the addition of 0.7% of highly overheated flour (treated at 180° F. (82.2° C.) for ten hours) to ordinary flour brings about a marked improvement in baking quality, comparable to the effect of chemical improvers. The addition of the heat-treated flour is stated to increase the stability of the dough, rendering it more elastic and less inclined to flow; these qualities are manifested especially in processes involving long fermentation, and with loaves not baked in tins. Kent-Jones ascribed the improvement in baking quality to an increased imbibitional capacity of the heated proteins. On the basis of these researches, several English patents have been granted.

Berliner and Ruter (2) attempted to repeat the findings of Kent-Jones. Their investigations of the effect of adding 0.7% overheated flour (so-called "K. J. flour") to ordinary flour failed to show any very marked improvement in the handling qualities of the dough. They used different flours, and varying baking technique; as a result, they observed a slight but no essential improvement, in no way comparable with the effect produced by chemical improvers, even when the fermentation time was extended to several hours. They also studied certain physical and chemical changes induced by heating the flour and, in the main, confirmed the findings of Kent-Jones. However, they criticised certain of the theoretical considerations advanced by the latter in explaining the cause of the phenomena which he observed.

Kent-Jones (21), in a discussion of Berliner and Ruter's work, criticizes conclusions based on experimental baking tests and points out that the final test is that of the baking trade. The opinion of Meikle (23), who carried out a commercial scale test of the value of adding overheated flour to normal flour, is quoted as evidence of the value of the process in stabilizing the dough in the Scotch commercial bakery practice.

Spousta (29) carried out a series of experiments to ascertain the extent to which the addition of flour heated to 180° F. (82.2° C.) to ordinary flour would improve the baking qualities of the latter. In these experiments a top patent flour was heated at 180° F. (82.2° C.) in closed containers. Baking tests carried out on the original flour alone, and also with the addition of




*The influence of time and temperature of heating on the baking quality of flour. (Graph, after Kent-Jones). Flour, wheat treated with natural moisture content.*

0.7%, 2% and 5% of the heat treated material, indicated no increase in loaf volume. The volume was apparently the only criterion of baking quality considered.

The Associate Committee on Grain Research of the National Research Council of Canada (24) have reported the results of their investigations on the drying of wheat by means of heat. This Committee had the co-operation of four Cereal Chemistry laboratories, and consequently the results represent mainly the average of four independent tests of all samples.

Studies were made on samples dried by means of heat in commercial driers and also in an experimental drier in which the various drying conditions, such as air temperature, rate of air flow, and rate of movement of the grain through the drier could be accurately controlled and measured.

There was no significant difference found between the yield of flour experimentally milled from the heat dried samples and that of flour from the corresponding air dried samples used as controls, but the ash content of the former was somewhat lower.

Baking tests showed that wheat could be artificially dried under proper conditions without injury to the baking quality. Damage to baking quality as determined by tests performed on commercially dried samples was found to be associated with the use of air temperatures above 180° F. (82.2° C.), the heating of excessively damp wheat, and drying to a low moisture content. The results submitted showed no significant change in the percent absorption of the flour. In relatively few cases did the undamaged samples reveal a baking quality superior to that of the control samples.

Tests carried out on experimentally dried samples confirmed the conclusion that 180° F. (82.2° C.) was the maximum safe temperature of the drying air, and showed, furthermore, that above this point the extent of the injury was roughly proportional to the rise in temperature. Under the more carefully controlled conditions in the experimental drier, the initial moisture content of the grain, even when it exceeded 18%, was not apparently a factor in the injury to baking quality. A close relation was found to exist between the maximum temperature of the hot grain and its final moisture content; this indicates that overdrying wheat involves a grave risk of raising its temperature to an injurious point, even though that of the drying air does not exceed 180° F. (82.2°C.).

More recently Sherwood (27) reported the results of a series of tests carried out in an experimental drier so constructed as to permit of its operation either as a direct drier (in which hot flue gases from the burning fuel are drawn from the furnace and, together with air, are forced through the grain), or as an indirect drier (in which air heated by passing over steam coils is the drying medium). Facilities were also provided for the use of air which had passed through the "cooler" section of the drier. Numerous experiments were carried out, in which drying air at a temperature not exceeding 175° F. (79.5° C.) was passed through wheat of approximately 16.0% moisture content; they revealed no recognizable damage to the wheat affecting the milling and baking

properties when continuous flow of the wheat through the drier was permitted. The wheat was dried to an average moisture of approximately 13.0%. Under these conditions both the indirect and direct methods were found satisfactory, and no damage resulted with the indirect method when air which had passed through the cooling section was used for drying. No appreciable absorption of sulphur dioxide by the wheat was detected in the indirect method, using coke containing 0.56% sulphur.

## Problem

The present investigation was undertaken in view of the conflicting reports in the literature on the possibility of improving the baking quality of flour by means of heat, and of the great economic importance of ascertaining the relative influence of moisture content, time and temperature of heating in relation to the commercial drying of wheat. With regard to the latter, it is desired to point out that these three variables cannot be studied individually, when the heating is conducted under conditions which permit moisture loss during the process. During each successive interval of time, the moisture content becomes less, the cooling effect of evaporation decreases, and the temperature of the wheat rises, resulting in a continually changing moisture content and wheat temperature.

The investigations reported in this study were made in order to determine the influence of the conditions of heating on the baking quality, and on those physico-chemical and chemical properties of wheat flour which are related to strength.

## Experimental

### Apparatus for the Heat Treatment of Wheat or Flour[1]

An adequate means of uniformly heating wheat or flour without moisture loss was the first requisite in carrying out this investigation. Kent-Jones (19) placed his experimental material in zinc slots, one inch wide, which were then immersed for various lengths of time in baths at different temperatures. In the case of short immersions these slots were shaken every five minutes. Temperature readings, submitted by this investigator, show that wheat placed in a bath, maintained at 43.5° C., reached a temperature of 42.0° C. in 30 minutes. Owing to the low thermal conductivity of wheat, a difference in temperature was undoubtedly set up during the heating which would cause some distillation of moisture from the hotter to the colder regions of the samples. An apparatus was, therefore, devised to meet this difficulty, and to secure, as nearly as possible, uniform heating of the samples.

The apparatus comprised three main units, (a) an eccentrically mounted drum, (b) an angle iron frame, to support the bearings of the drum and other moving parts, and (c) a chain and shaft drive, so arranged as to drive the drum

[1] *The writer is indebted to Mr. D. S. Binnington, of the Chemistry Department, for assistance in devising this apparatus, and also to Prof. G. L. Shanks, Mr. H. Robson and Mr. R. Mitchell, of the Engineering Department, Manitoba Agricultural College, for its construction, working drawing and description.*

at a speed of 28 r.p.m.; a working drawing of the apparatus is shown in Fig. 1. The drum consisted of a copper cylinder with a volume, exclusive of the pocket beneath the handhole cover, of approximately 510 cu. in. A boss was placed on each end of the drum so that the axis extended diagonally across from one end to the other. This arrangement caused the drum to run off center about 2.5 in., and to produce a combined rolling and end to end motion which

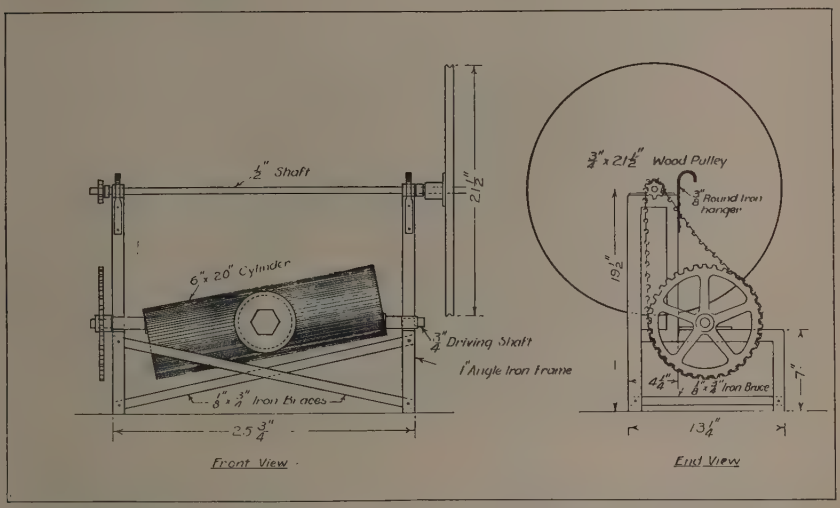



FIG. 1. *Working Drawing of Apparatus Used in Heat Treatment of Wheat and Flour.*

effectively stirred the contents. To gain access to the interior of the drum a handhole, 5 in. inside diameter, was brazed to the center of the drum. The handhole was closed by means of a screw-threaded cover fitting against a leather gasket. After assembling, the inside of the drum was thoroughly tinned. The apparatus was driven by a 0.25 h.p. electric motor.

The drum was kept immersed in a constant temperature oil bath which could be maintained within $\pm 0.1°$ C. of any temperature between 20° C. and 135° C. The assembled apparatus is shown in Plate II.

On completion of the treatment, the drum was hoisted from the constant temperature bath and rotated in cold water for ten minutes, in order to cool the contents quickly, thus eliminating as far as possible, a lag in the heat treatment.

## THE INFLUENCE OF VARYING THE CONDITIONS OF HEATING ON THE BAKING QUALITY OF FLOUR

The investigations reported in this paper were conducted on flour milled from Western Canadian hard red spring wheat; 600 lb of an unbleached standard patent or straight-grade flour of 74% extraction was supplied by the Western Canada Flour Mills Company, Ltd., Winnipeg, together with 150

lb of the mill mix from which this flour was milled. The crude protein content of the wheat and flour (expressed on the basis of dry material) was 15.41% and 13.90% respectively and the ash content of the flour, 0.62%. The flour, secured in October 1928, was milled from new crop wheat so that there was little opportunity for aging; it was stored in well-filled, sealed, air-tight containers at a temperature of approximately 12° C., portions being withdrawn from storage only as required for use.

Heat treatments were undertaken immediately, the preliminary studies being made on the flour with its normal moisture content (13.90% as determined by drying in a vacuum oven). The graph prepared by Kent-Jones (Plate I) was used as a guide in selecting the temperature and duration for each treatment, numerous points being chosen in the three regions of the graph.

Portions of 1,200 gm of the unbleached straight-grade flour (13.90% moisture content) were used for each treatment and the sample stored in air-tight containers until the whole series of treatments was completed. A moisture determination was made on each sample of the flour after each treatment. The latter determinations were invariably slightly lower than that of the original flour, owing largely to exposure incident to removal of the sample from the heater, since the heating apparatus was air-tight. In no case did the decrease in moisture exceed 0.6%.

No significant change in the physical properties of the flour was observed at treatments below 160° F. (71.1°C.). At this and at higher temperatures changes in the "feel" of the flour became manifest particularly in the longer treatments. The flour gradually became more granular in nature and ran through the fingers much like very fine sand. The color also became slightly darker.

When the entire series of treatments was completed the samples were transferred from the tin containers to small bags which were suspended in a room maintained at a relative humidity of approximately 70% and a temperature of 18° C. for 35 days. This allowed for some aging to take place prior to the baking tests.

It is beyond the scope of this paper to review the extensive literature relating to the various procedures used in test baking. The development of the experimental baking test has recently been adequately reviewed by Brooke and Sherwood (9) and need not be detailed here. The investigations of Werner (30), and Herman and Hart (15) provided the foundation for the development of a standard baking test based on scientific principles. Blish (4, 5) pointed out the advantages of a fixed baking method and later, as chairman of the Committee on Standardization of the Experimental Baking Test of the American Association of Cereal Chemists (6), reported the details of the baking procedure proposed. This, as outlined in the above report, has recently been adopted, with certain minor modifications, by the Associate Committee on Grain Research of the National Research Council of Canada in their collaborative work. This modified procedure was, in all important essentials, used in these investigations.

*The heat treatment apparatus assembled for use*

The basic procedure—Blish (6)—was followed with respect to the proportions of yeast, salt and sugar, with the difference that 100 gm of flour on a 13.5% moisture basis determined by the vacuum oven method was used. The absorption was varied in order to produce a dough of the desired consistency. The doughs were mixed in a small Hobart mixer equipped with two hooks operated at No. 2 speed for three minutes. The loaves were baked in low-sided pans (top 4¼ in. × 2¾ in., bottom 3 11/16 in. × 2 1/16 in., depth 2 in.). In all other respects the conditions laid down in the basic procedure were adhered to and the method thus modified designated in this paper as the "standard" or "basic procedure". Absorption is only included in a few tables since in most instances the differences were not great; little significance can be attached to small differences in absorption when determined on 100 gm of flour.

The loaf volume was determined in the measuring device described by Geddes and Binnington (12).

The method of judging the loaves baked in this investigation was essentially that adopted by a Conference of Cereal Chemists working under the direction of the Associate Committee on Grain Research, (National Research Council of Canada). The characteristics of the bread were scored on a numerical scale, and where a score less than perfect was assigned, a letter was appended indicating the type of fault for which the loaf was scored down, (where no letter was appended the fault was not well defined). The following factors were considered in scoring the loaves, and in assigning the key letter:

### I. Crust Color—Perfect Score 5

P = Color paler than ideal, D = Color darker than ideal.

### II. General Appearance—Perfect Score 5

Under this heading were included external characteristics other than color, particularly those characteristics associated with an under-fermented or over-fermented dough.

g = green or under-fermented,

O = characteristics associated with an over-fermented dough.

### III. Grain and Texture—Perfect Score 10

Grain and texture were considered together, the usual significance of these terms being employed.

C = coarse, c = close, O = open.

Crumb color was not considered in this study, since the same flour was used throughout and differences in texture profoundly influence the crumb color.

That the baking results might be of more significance, the judging was done by one unfamiliar with the treatment the samples had received[1]. Approximately 60 loaves were baked per day, so that changes incidental to aging were

[1] *The baked loaves were submitted to Mr. A. W. Alcock, Chief Chemist of the Western Canada Flour Mills, Ltd., Winnipeg, an experienced test baker and judge of bread, to whom the writer is greatly indebted for his assistance in judging some 1,400 loaves baked in connection with these studies.*

reduced to a minimum. All the samples were baked in duplicate, the check bakings made on different days. Where the loaf volumes failed to agree within 20 cc. the bakings were repeated until results came within these limits.

Since neither Kent-Jones (19) nor Berliner and Ruter (2), published any of their baking results, it seemed worth while to describe in detail the results obtained with these samples. The mean results are given in Table I. (The values for the control sample are the mean of 14 bakings.)

A noticeable improvement in the handling qualities of the doughs made from flours heated at the lower temperatures was observed, more particularly early in the fermentation. The doughs were somewhat more springy, slightly less sticky, and rounded up to form a smoother ball than the control. With more severe treatments, the doughs lacked resiliency and "life", and had to be mixed with less water; in mixing, the mass did not hold together, and these doughs were very difficult to mould without tearing, due to their "shortness".

A perusal of Table I reveals no significant change in volume with the lower heat treatments, but marked decreases with the more severe treatments.

The alteration in crust characteristics aside from color, even with the lower heat treatments, was very marked. The bread baked from the control flour exhibited crust characteristics associated with slightly "green" or young dough,—namely sharp corners, small round gas holes, and smooth, glossy sides. Even with the lowest heat treatment (130° F. or 54.4° C. for two hours) these characteristics were less marked. With increasing heat, changes in the color of the crust became evident; it grew paler and paler until it assumed a greyish white. The "green" features of the crust disappeared and were gradually replaced by characteristics associated with an over-fermented dough. Break and shred gradually decreased until they were entirely lacking, the corners became more and more rounded, and the sides increasingly rough.

Changes in the texture of the crumb were also pronounced. Even with the lowest heat treatment a decided improvement in texture over the control loaves was observed. The control loaf possessed a slightly coarse and open texture, while the loaves baked from the lower treatments had much finer crumb and showed less tendency to "open". As the heat treatments increased, the texture became very "close" and "coarser", until finally all semblance to normal bread texture was lost.

The characteristics described above may be discerned from the photographs in Plate III, showing the improvement and degradation in baking quality due to heat treatment.

In view of the results obtained by the basic formula, it appeared advisable to determine the effect of adding 0.001% potassium bromate to the baking formula.

Discussions of various aspects of the "bromate differential test" have been published by Herman (14), by Blish and Sandstedt (7), by Werner and Herman (31), and by Larmour and MacLeod (22). It is apparently the concensus of opinion among experienced users of the bromate test, that it supplies a means for the estimation of gluten quality; positive responses are associated with

*The improvement and degradation in baking quality due to heat treatment of straight-grade flour (treated at 13.90% moisture). Labels designate temperature in °C. and time in hours. (54.4°C. = 130°F., 57.2°C. = 135°F., 76.7°C. = 170°F.).*

## TABLE I

THE INFLUENCE OF TIME AND TEMPERATURE OF HEATING ON THE BAKING QUALITY OF UNBLEACHED STRAIGHT-GRADE FLOUR (MOISTURE CONTENT 13.90%)*

| Treatment | | Absorption per cent | Loaf volume in cc. | General appearance | Crust color | Grain and texture |
|---|---|---|---|---|---|---|
| Temp. in ° F. | Time in hr | | | | | |
| Control | | 61 | 560 | 3.1 g | 5.0 | 6.7 C&O |
| 130 | 2 | 63 | 572 | 3.2 g | 5.0 | 8.5 C |
| 130 | 4 | 63 | 580 | 3.3 g | 5.0 | 8.5 C |
| 130 | 8 | 61 | 545 | 3.8 | 5.0 | 7.8 C |
| 130 | 16 | 62 | 571 | 3.3 | 5.0 | 8.8 C |
| 130 | 24 | 63 | 561 | 3.3 | 5.0 | 8.3 C |
| 135 | 2 | 62 | 562 | 3.2 g | 5.0 | 8.6 C |
| 135 | 4 | 62 | 555 | 3.2 g | 5.0 | 8.6 C |
| 135 | 8 | 61 | 552 | 3.7 | 5.0 | 7.8 C |
| 135 | 16 | 62 | 534 | 3.3 | 5.0 | 9.0 C |
| 135 | 24 | 62 | 561 | 3.3 | 5.0 | 8.3 C |
| 140 | 1 | 62 | 564 | 3.1 g | 5.0 | 8.0 C |
| 140 | 2 | 62 | 568 | 3.2 g | 5.0 | 8.2 C |
| 140 | 4 | 62 | 552 | 3.3 | 5.0 | 8.0 C |
| 140 | 6 | 62 | 567 | 3.2 | 5.0 | 8.0 C |
| 140 | 8 | 62 | 563 | 3.8 | 5.0 | 7.8 C |
| 140 | 16 | 61 | 525 | 3.4 | 4.7 P | 8.0 C |
| 140 | 24 | 62 | 530 | 3.4 | 4.5 P | 7.8 C |
| 145 | 1 | 62 | 558 | 3.1 g | 5.0 | 7.8 C |
| 145 | 2 | 62 | 559 | 3.3 | 5.0 | 7.8 C |
| 145 | 3 | 62 | 553 | 3.3 | 5.0 | 8.3 C |
| 145 | 4 | 62 | 557 | 3.4 | 5.0 | 7.8 C |
| 145 | 6 | 62 | 562 | 3.3 | 5.0 | 8.0 C |
| 145 | 8 | 60 | 537 | 3.7 | 5.0 | 7.8 C |
| 145 | 10 | 61 | 537 | 3.4 O | 4.3 P | 7.2 C |
| 150 | 0.5 | 62 | 553 | 3.2 g | 5.0 | 7.3 C |
| 150 | 1 | 62 | 548 | 3.3 | 5.0 | 7.3 C |
| 150 | 2 | 62 | 547 | 3.2 | 4.8 P | 8.1 C |
| 150 | 3 | 62 | 579 | 3.4 O | 5.0 | 8.5 C |
| 150 | 4 | 62 | 572 | 3.4 O | 4.8 P | 7.8 C |
| 150 | 6 | 61 | 559 | 3.4 O | 5.0 | 8.3 C |
| 150 | 8 | 60 | 512 | 3.8 | 5.0 | 7.5 C |
| 150 | 10 | 61 | 517 | 3.2 O | 4.0 P | 7.6 C |
| 150 | 16 | 61 | 500 | 3.2 O | 4.0 P | 8.4 C |
| 155 | 0.5 | 62 | 575 | 3.2 g | 5.0 | 7.2 C |
| 155 | 1 | 62 | 565 | 3.3 | 5.0 | 8.2 C |
| 155 | 2 | 62 | 541 | 3.3 | 5.0 | 8.1 C |
| 155 | 3 | 62 | 555 | 3.4 | 5.0 | 8.3 C |
| 155 | 4 | 62 | 527 | 3.3 O | 4.3 P | 8.1 C |
| 155 | 6 | 61 | 496 | 3.4 O | 4.3 P | 7.0 C |
| 155 | 8 | 60 | 500 | 3.7 O | 4.2 P | 7.5 C |
| 155 | 10 | 61 | 441 | 2.7 O | 3.3 P | 6.4 C&c |
| 160 | 0.25 | 61 | 548 | 3.3 g | 5.0 | 7.1 C |
| 160 | 0.5 | 61 | 533 | 3.5 | 5.0 | 7.4 C |
| 160 | 0.75 | 61 | 533 | 3.6 | 4.8 P | 7.9 C |
| 160 | 1.0 | 61 | 515 | 3.7 O | 4.8 P | 7.6 C |
| 160 | 1.5 | 61 | 529 | 3.7 O | 4.5 P | 7.3 C |
| 160 | 2 | 60 | 521 | 3.7 O | 4.6 P | 7.4 C |
| 160 | 3 | 60 | 479 | 3.1 O | 4.3 P | 6.9 C&c |
| 160 | 4 | 60 | 414 | 2.6 O | 3.6 P | 6.4 C&c |
| 160 | 6 | 60 | 352 | 2.1 O | 2.8 P | 5.6 C&c |
| 160 | 8 | 60 | 340 | 1.9 O | 2.5 P | 5.0 C&c |
| 170 | 0.25 | 62 | 548 | 3.1 g | 4.8 P | 6.6 C |
| 170 | 0.5 | 62 | 520 | 3.3 | 4.5 P | 7.3 C |
| 170 | 0.75 | 62 | 452 | 2.9 O | 3.3 P | 5.9 C&c |
| 170 | 1.0 | 61 | 384 | 2.4 O | 2.5 P | 4.8 C&c |
| 170 | 1.5 | 60 | 358 | 2.1 O | 3.0 P | 5.8 C&c |
| 170 | 2 | 60 | 323 | 2.1 O | 2.4 P | 4.9 C&c |
| 170 | 3 | 60 | 279 | 1.5 O | 1.6 P | 4.0 C&c |
| 170 | 4 | 60 | 261 | 1.5 O | 1.4 P | 3.2 C&c |
| 170 | 6 | 60 | 229 | 0.7 O | 1.0 P | 2.5 C&c |
| 170 | 8 | 60 | 213 | 0.3 O | 0.7 P | 2.0 C&c |
| 180 | 0.25 | 62 | 491 | 3.1 O | 3.5 P | 6.6 C |
| 180 | 0.5 | 61 | 333 | 2.3 O | 1.4 P | 3.5 C&c |
| 180 | 0.75 | 61 | 290 | 1.1 O | 0.5 P | 2.0 C&c |
| 180 | 1.0 | 61 | 271 | 0.5 O | 0.4 P | 2.0 C&c |
| 190 | 0.25 | 61 | 324 | 1.9 O | 1.3 P | 3.5 C&c |
| 190 | 0.5 | 60 | 259 | 0.3 O | 0.0 P | 1.0 C&c |

**Comparative baking tests (basic procedure)*

## TABLE II

THE INFLUENCE OF TIME AND TEMPERATURE OF HEATING ON THE BAKING QUALITY OF UNBLEACHED STRAIGHT-GRADE FLOUR (MOISTURE CONTENT 13.90%)*

| Treatment | | Loaf volume in cc. | General appearance | Crust color | Grain and texture |
|---|---|---|---|---|---|
| Temperature in °F. | Time, in hr | | | | |
| Control | | 635 | 4.6 | 5.0 | 8.6 |
| 130 | 2 | 605 | 4.7 | 4.9 P | 8.8 |
| 130 | 4 | 599 | 4.6 | 4.9 P | 8.3 |
| 130 | 8 | 589 | 4.4 | 4.8 P | 8.7 |
| 130 | 16 | 583 | 4.5 | 4.6 P | 8.8 |
| 130 | 24 | 560 | 3.9 O | 4.5 P | 8.9 |
| 135 | 2 | 603 | 3.8 O | 4.9 P | 8.9 |
| 135 | 4 | 594 | 4.3 | 4.9 P | 7.9 |
| 135 | 8 | 585 | 3.5 | 4.6 P | 8.8 |
| 135 | 16 | 543 | 3.7 O | 4.3 P | 8.5 |
| 135 | 24 | 526 | 3.2 O | 4.0 P | 8.3 |
| 140 | 1 | 633 | 3.8 | 5.0 | 8.3 |
| 140 | 2 | 610 | 4.4 | 5.0 | 7.5 |
| 140 | 4 | 600 | 4.3 | 4.8 P | 8.5 |
| 140 | 6 | 582 | 4.1 | 4.3 P | 8.0 |
| 140 | 8 | 554 | 3.6 | 4.2 P | 9.0 |
| 140 | 16 | 492 | 3.2 O | 4.1 P | 7.3 C&c |
| 140 | 24 | 473 | 3.0 O | 4.0 P | 6.9 C&c |
| 145 | 1 | 640 | 3.8 | 5.0 | 8.6 |
| 145 | 2 | 605 | 4.4 | 4.9 P | 8.6 |
| 145 | 3 | 601 | 4.3 | 4.9 P | 8.1 |
| 145 | 4 | 594 | 3.8 | 4.8 P | 8.4 |
| 145 | 6 | 589 | 3.1 O | 4.8 P | 8.5 |
| 145 | 8 | 540 | 3.5 O | 4.5 P | 8.5 |
| 145 | 10 | 500 | 2.8 O | 4.3 P | 7.1 C&c |
| 150 | 0.5 | 640 | 4.5 | 5.0 | 8.6 |
| 150 | 1 | 630 | 4.5 | 5.0 | 8.6 |
| 150 | 2 | 586 | 4.3 | 4.6 P | 8.8 |
| 150 | 3 | 560 | 4.2 | 4.4 P | 8.5 |
| 150 | 4 | 539 | 3.2 O | 4.5 P | 7.8 |
| 150 | 6 | 527 | 3.2 O | 4.4 P | 7.9 |
| 150 | 8 | 487 | 2.7 O | 4.4 P | 7.0 C&c |
| 150 | 10 | 443 | 2.6 O | 4.1 P | 6.4 C&c |
| 150 | 16 | 421 | 2.3 O | 3.6 P | 5.8 C&c |
| 155 | 0.5 | 611 | 4.4 | 4.9 P | 8.8 |
| 155 | 1 | 593 | 4.3 | 5.0 | 8.3 |
| 155 | 2 | 558 | 3.9 | 4.8 P | 7.6 |
| 155 | 3 | 522 | 3.1 O | 4.5 P | 7.0 |
| 155 | 4 | 487 | 3.4 O | 4.5 P | 6.6 C&c |
| 155 | 6 | 425 | 2.4 O | 3.3 P | 5.0 C&c |
| 155 | 8 | 452 | 2.6 O | 4.0 P | 6.5 C&c |
| 155 | 10 | 352 | 1.9 O | 2.9 P | 4.5 C&c |
| 160 | 0.25 | 600 | 4.4 | 4.8 P | 8.1 |
| 160 | 0.5 | 611 | 4.2 | 4.8 P | 8.9 |
| 160 | 0.75 | 551 | 3.5 | 4.4 P | 7.8 |
| 160 | 1.0 | 541 | 3.3 O | 4.5 P | 7.8 |
| 160 | 1.5 | 490 | 2.9 O | 4.5 P | 7.1 C&c |
| 160 | 2 | 486 | 2.7 O | 4.4 P | 7.0 C&c |
| 160 | 3 | 422 | 2.4 O | 3.5 P | 5.9 C&c |
| 160 | 4 | 325 | 1.9 O | 2.8 P | 5.1 C&c |
| 160 | 6 | 283 | 1.3 O | 1.8 P | 3.3 C&c |
| 160 | 8 | 287 | 1.1 O | 1.5 P | 2.8 C&c |
| 170 | 0.25 | 562 | 4.4 | 5.0 | 9.0 |
| 170 | 0.5 | 455 | 3.0 O | 4.0 P | 6.0 C&c |
| 170 | 0.75 | 402 | 2.5 O | 3.3 P | 5.5 C&c |
| 170 | 1.0 | 343 | 1.9 O | 2.9 P | 5.0 C&c |
| 170 | 1.5 | 292 | 1.5 O | 1.6 P | 3.4 C&c |
| 170 | 2 | 271 | 1.3 O | 1.3 P | 2.4 C&c |
| 170 | 3 | 240 | 0.5 O | 0.6 P | 1.3 C&c |
| 170 | 4 | 229 | 0.4 O | 0.3 P | 0.8 C&c |
| 170 | 6 | 210 | 0.0 O | 0.0 P | 0.4 C&c |
| 170 | 8 | 197 | 0.0 O | 0.0 P | 0.0 C&c |
| 180 | 0.25 | 405 | 2.5 O | 3.1 P | 5.6 C&c |
| 180 | 0.5 | 272 | 0.9 O | 1.0 P | 2.3 C&c |
| 180 | 0.75 | 244 | 0.4 O | 0.5 P | 1.4 C&c |
| 180 | 1.0 | 205 | 0.4 O | 0.8 P | 2.4 C&c |
| 190 | 0.25 | 269 | 0.9 O | 1.5 P | 3.0 C&c |
| 190 | 0.5 | 206 | 0.1 O | 0.6 P | 1.5 C&c |

*Comparative baking tests—basic procedure plus 0.001% potassium bromate.*

high gluten quality, while negative responses indicate poor gluten quality or over-oxidation of the flour prior to the test. Results obtained in the present investigation, however, have led to the expression of somewhat different views.

The results of comparative baking tests with the addition of 0.001% potassium bromate to the basic formula are given in Table II. They revealed throughout a decreased baking quality due to heat treatment. The control flour gave a marked positive response to bromate with regard to all bread characteristics. On the other hand, the heat treated flours showed a decrease in loaf volume, and no improvement in crust characteristics, or grain and texture, when compared with the control flour. The same trend towards the characteristics of an over-fermented loaf with increasing severity of heat treatment was observed, but the effects were more pronounced and became evident at lower treatments. These characteristics are illustrated in Plate IV.

The claim of Kent-Jones (19) that heat treatment increases the "stability" or fermentation tolerance, a property much desired by commercial bakers, was next investigated. Preliminary tests were conducted on the control flour, by the basic procedure, varying the fermentation time from one to five hours by 45-minute intervals. There was a gradual and progressive change in the bread characteristics, with no pronounced signs of exhaustion or alteration in visible physical properties.

The experiment was repeated with the addition of 0.001% potassium bromate to the formula—Blish and Sandstedt (7), pointed out the value of bromate in determining fermentation tolerance. As a result, fermentation times of 1.75, 3, and 4.25 hours were chosen as giving the characteristics of a slightly under-fermented, a correctly fermented, and on over-fermented dough respectively. The whole series of flours were baked in this manner, the ratio of the times between the two punches and moulding being 9:4:2.

The baking results are recorded in Tables III and IV, and a summary of the baking results obtained by different methods is given in Table V.

For purposes of general discussion and a comparison of the relative baking quality of the different flours, it is desirable to secure a single figure expressive of bread quality. Saunders, Nichols and Cowan (26), Larmour and MacLeod (22), and others have used different methods in computing an arbitrary baking score including various bread characteristics. The tendency of American chemists has been to place major emphasis on loaf volume, probably since this property of the baked loaf is subject to quantitative expression; its acceptability as an accurate index of strength was defended by Briggs (8). In this study, however, it seemed advisable to give some weight to general appearance, crust color, and grain texture, since these characteristics form an important index of quality; they already showed significant variations, due to heat treatment, before appreciable differences in loaf volume were observed.

The final baking score was computed as follows:

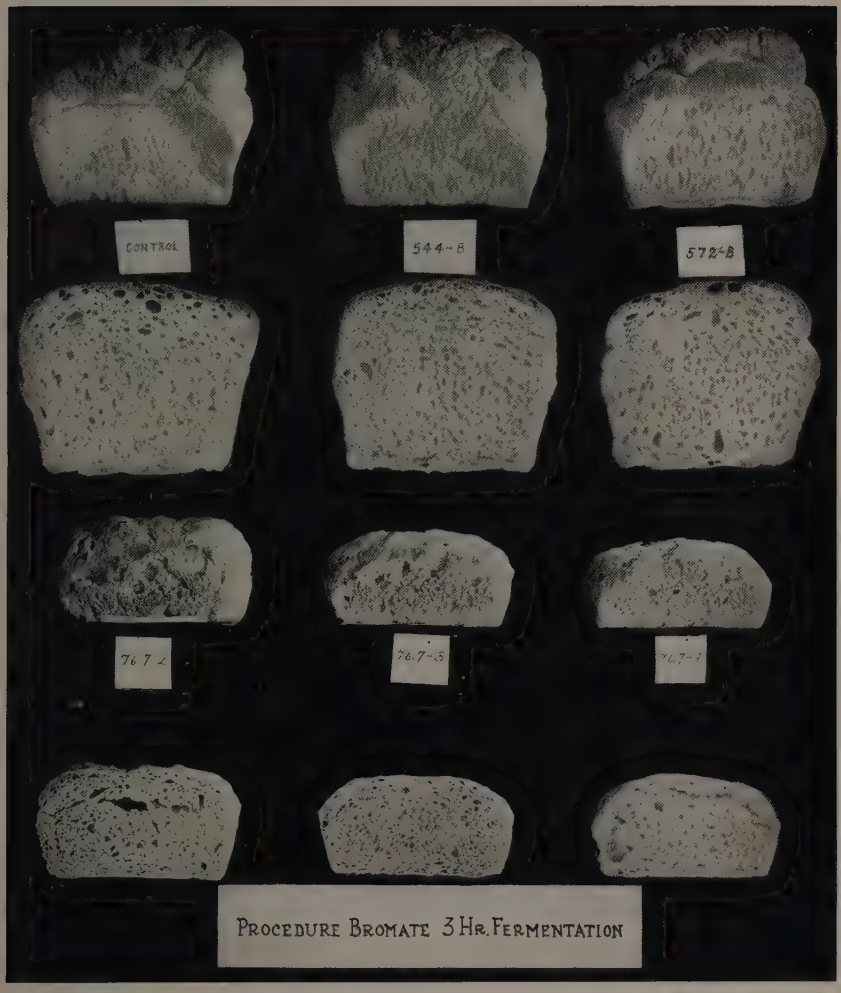
Loaf volume in cc. $\times$ 0.1, score for general appearance, score for crust color, and score for grain and texture $\times$ 3.

## TABLE III

INFLUENCE OF TIME AND TEMPERATURE OF HEATING ON THE BAKING QUALITY OF UNBLEACHED STRAIGHT-GRADE FLOUR (HEAT TREATED AT 13.90% MOISTURE)*

| Treatment | | Loaf volume in cc. | General appearance | Crust color | Grain and texture |
|---|---|---|---|---|---|
| Temperature in ° F. | Time, in hr | | | | |
| Control | | 603 | 4.0 g | 4.8 D | 8.3 C |
| 130 | 2 | 615 | 4.2 g | 4.8 D | 8.3 C |
| 130 | 4 | 583 | 4.2 g | 4.8 D | 8.3 C |
| 130 | 8 | 570 | 4.3 g | 4.8 D | 8.5 C |
| 130 | 16 | 599 | 4.6 | 4.8 D | 8.8 C |
| 130 | 24 | 575 | 4.6 | 5.0 | 9.0 C |
| 135 | 2 | 621 | 4.4 g | 4.8 D | 8.3 C |
| 135 | 4 | 607 | 4.7 | 4.8 D | 8.3 C |
| 135 | 8 | 562 | 4.7 | 4.9 D | 8.9 C |
| 135 | 16 | 550 | 4.0 O | 4.9 D | 8.3 C |
| 135 | 24 | 511 | 4.3 O | 4.9 D | 8.5 C |
| 140 | 1 | 592 | 4.5 | 4.9 D | 8.6 C |
| 140 | 2 | 573 | 4.4 | 4.8 D | 8.6 C |
| 140 | 4 | 577 | 4.5 | 4.8 D | 8.4 C |
| 140 | 6 | 569 | 4.5 | 4.9 D | 7.8 C |
| 140 | 8 | 539 | 4.4 | 5.0 | 8.0 C |
| 140 | 16 | 524 | 3.9 O | 5.0 | 8.0 C |
| 140 | 24 | 492 | 3.3 O | 4.8 P | 6.5 C&c |
| 145 | 1 | 585 | 4.4 | 4.8 D | 7.9 C |
| 145 | 2 | 585 | 4.4 | 5.0 | 8.8 C |
| 145 | 3 | 565 | 4.5 | 5.0 | 8.9 C |
| 145 | 4 | 566 | 4.4 | 5.0 | 8.3 C |
| 145 | 6 | 550 | 4.4 | 5.0 | 8.5 C |
| 145 | 8 | 522 | 3.6 O | 4.5 P | 8.3 C |
| 145 | 10 | 505 | 3.4 O | 4.5 P | 7.5 C |
| 150 | 0.5 | 605 | 4.4 | 4.8 D | 8.5 C |
| 150 | 1 | 592 | 4.4 | 4.8 D | 8.6 C |
| 150 | 2 | 571 | 4.4 | 4.8 D | 8.3 C |
| 150 | 3 | 574 | 4.4 | 5.0 | 8.8 C |
| 150 | 4 | 561 | 4.2 O | 4.5 P | 8.0 C |
| 150 | 6 | 532 | 4.0 O | 5.0 | 8.1 C |
| 150 | 8 | 516 | 3.7 O | 5.0 | 7.1 C |
| 150 | 10 | 488 | 3.1 O | 4.5 P | 6.0 C&c |
| 150 | 16 | 458 | 2.9 O | 3.5 P | 5.6 C&c |
| 155 | 0.5 | 600 | 4.4 g | 4.8 D | 8.3 C |
| 155 | 1 | 585 | 4.2 g | 4.8 D | 8.5 C |
| 155 | 2 | 564 | 4.6 | 4.8 D | 8.4 C |
| 155 | 3 | 541 | 4.7 | 5.0 | 8.0 C |
| 155 | 4 | 510 | 3.5 O | 4.9 P | 7.1 C |
| 155 | 6 | 468 | 3.2 O | 4.5 P | 5.7 C&c |
| 155 | 8 | 440 | 3.0 O | 4.2 P | 5.7 C&c |
| 155 | 10 | 380 | 2.0 O | 3.8 P | 4.8 C&c |
| 160 | 0.25 | 592 | 4.4 g | 4.8 D | 8.3 C |
| 160 | 0.5 | 568 | 4.2 g | 4.8 D | 7.4 C |
| 160 | 0.75 | 554 | 4.5 | 4.9 P | 8.0 C |
| 160 | 1.0 | 562 | 4.4 O | 4.9 P | 8.1 C |
| 160 | 1.5 | 506 | 3.4 O | 4.9 P | 6.9 C |
| 160 | 2 | 498 | 3.4 O | 4.9 P | 7.1 C |
| 160 | 3 | 423 | 3.1 O | 4.1 P | 6.3 C&c |
| 160 | 4 | 361 | 2.6 O | 3.1 P | 4.0 C&c |
| 160 | 6 | 296 | 1.9 O | 2.8 P | 2.6 C&c |
| 160 | 8 | 281 | 1.7 O | 2.1 P | 2.4 C&c |
| 170 | 0.25 | 565 | 4.7 | 4.9 D | 8.5 C |
| 170 | 0.5 | 465 | 3.8 O | 4.6 P | 6.8 C&c |
| 170 | 0.75 | 417 | 3.4 O | 4.5 P | 5.3 C&c |
| 170 | 1.0 | 329 | 2.3 O | 3.1 P | 3.1 C&c |
| 170 | 1.5 | 310 | 2.1 O | 2.4 P | 3.0 C&c |
| 170 | 2 | 285 | 1.5 O | 1.9 P | 1.5 C&c |
| 170 | 3 | 243 | 0.7 O | 1.4 P | 0.8 C&c |
| 170 | 4 | 247 | 0.5 O | 0.4 P | 0.0 C&c |
| 170 | 6 | 226 | 0.5 O | 0.3 P | 0.0 C&c |
| 170 | 8 | 212 | 0.3 O | 0.1 P | 0 0 C&c |
| 180 | 0.25 | 432 | 3.4 O | 4.4 P | 5.6 C&c |
| 180 | 0.5 | 281 | 1.5 O | 1.6 P | 1 8 C&c |
| 180 | 0.75 | 242 | 0.9 O | 1.0 P | 1.0 C&c |
| 180 | 1.0 | 213 | 0.7 O | 0.9 P | 0.5 C&c |
| 190 | 0.25 | 253 | 0.7 O | 1.6 P | 1.1 C&c |
| 190 | 0.5 | 222 | 0.7 O | 0 3 P | 0.3 C&c |

*Comparative baking tests; fermentation time 1:75 hours. Bromate method*




*The changes in baking quality due to heat treatment of straight-grade flour (treated at 13.90% moisture). Labels designate temperature in °C. and time in hours. (54.4°C. = 135°F., 57.2°C. = 135°F., 76.7°C. = 170°F.).*

TABLE IV

INFLUENCE OF TIME AND TEMPERATURE OF HEATING ON THE BAKING QUALITY (BROMATE PROCEDURE) OF UNBLEACHED STRAIGHT-GRADE FLOUR (HEAT TREATED AT 13.90% MOISTURE)*

| Treatment | | Loaf volume in cc. | General appearance | Crust color | Grain and texture |
|---|---|---|---|---|---|
| Temperature in ° F. | Time, in hr | | | | |
| Control | | 615 | 4.0 O | 4.3 P | 8.8 C |
| 130 | 2 | 606 | 4.0 O | 4.4 P | 8.5 C |
| 130 | 4 | 602 | 4.0 O | 4.9 P | 8.5 C |
| 130 | 8 | 561 | 3.8 O | 4.5 P | 8.5 C |
| 130 | 16 | 555 | 4.0 O | 4.1 P | 8.4 C |
| 130 | 24 | 537 | 4.0 O | 4.0 P | 8.1 C |
| 135 | 2 | 610 | 4.2 O | 4.9 P | 8.1 C |
| 135 | 4 | 564 | 3.8 O | 4.4 P | 8.1 C |
| 135 | 8 | 541 | 3.5 O | 4.6 P | 7.6 C |
| 135 | 16 | 563 | 3.7 O | 3.6 P | 7.9 C |
| 135 | 24 | 472 | 3.4 O | 3.8 P | 7.6 C |
| 140 | 1 | 595 | 4.2 O | 4.4 P | 8.3 C |
| 140 | 2 | 575 | 4.0 O | 4.8 P | 8.3 C |
| 140 | 4 | 580 | 3.9 O | 4.6 P | 8.1 C |
| 140 | 6 | 558 | 4.2 O | 4.5 P | 8.1 C |
| 140 | 8 | 545 | 3.9 O | 4.1 P | 7.9 C |
| 140 | 16 | 497 | 3.0 O | 3.8 P | 7.6 C |
| 140 | 24 | 432 | 2.4 O | 3.0 P | 6.5 C |
| 145 | 1 | 619 | 3.9 O | 4.8 P | 8.3 C |
| 145 | 2 | 571 | 3.9 O | 4.1 P | 8.0 C |
| 145 | 3 | 556 | 3.6 O | 3.9 P | 7.9 C |
| 145 | 4 | 532 | 3.8 O | 3.9 P | 8.0 C |
| 145 | 6 | 506 | 3.4 O | 4.1 P | 7.8 C |
| 145 | 8 | 500 | 3.6 O | 3.9 P | 8.0 C |
| 145 | 10 | 452 | 2.3 O | 3.3 P | 6.4 C&c |
| 150 | 0.5 | 623 | 4.0 O | 4.8 P | 8.9 C |
| 150 | 1 | 592 | 4.2 O | 4.3 P | 8.3 C |
| 150 | 2 | 571 | 4.0 O | 4.4 P | 8.3 C |
| 150 | 3 | 535 | 3.6 O | 4.3 P | 7.6 C |
| 150 | 4 | 495 | 3.1 O | 3.6 P | 7.3 C |
| 150 | 6 | 473 | 2.6 O | 3.5 P | 7.4 C&c |
| 150 | 8 | 430 | 2.1 O | 3.4 P | 7.0 C&c |
| 150 | 10 | 416 | 1.9 O | 3.5 P | 5.9 C&c |
| 150 | 16 | 386 | 1.9 O | 2.9 P | 5.7 C&c |
| 155 | 0.5 | 553 | 3.8 O | 4.0 P | 8.5 C |
| 155 | 1 | 599 | 3.9 O | 4.6 P | 8.6 C |
| 155 | 2 | 510 | 3.2 O | 4.5 P | 8.1 C |
| 155 | 3 | 459 | 2.9 O | 4.3 P | 7.3 C&c |
| 155 | 4 | 422 | 2.1 O | 3.1 P | 6.1 C&c |
| 155 | 6 | 405 | 2.1 O | 2.8 P | 5.5 C&c |
| 155 | 8 | 407 | 2.1 O | 3.1 P | 6.3 C&c |
| 155 | 10 | 346 | 1.3 O | 2.4 P | 5.1 C&c |
| 160 | 0.25 | 582 | 4.0 O | 4.3 P | 8.5 C |
| 160 | 0.5 | 549 | 3.9 O | 4.3 P | 8.3 C |
| 160 | 0.75 | 510 | 3.5 O | 3.6 P | 7.9 C |
| 160 | 1.0 | 497 | 3.2 O | 3.4 P | 7.5 C&c |
| 160 | 1.5 | 444 | 2.8 O | 3.0 P | 8.0 C&c |
| 160 | 2 | 421 | 3.1 O | 3.5 P | 7.5 C&c |
| 160 | 3 | 370 | 2.6 O | 3.1 P | 6.3 C&c |
| 160 | 4 | 306 | 2.3 O | 2.0 P | 3.1 C&c |
| 160 | 6 | 279 | 1.7 O | 1.4 P | 2.8 C&c |
| 160 | 8 | 252 | 1.3 O | 1.3 P | 2.5 C&c |
| 170 | 0.25 | 512 | 3.4 O | 3.5 P | 7.6 C |
| 170 | 0.5 | 405 | 2.9 O | 2.9 P | 7.1 C&c |
| 170 | 0.75 | 355 | 2.6 O | 2.5 P | 5.3 C&c |
| 170 | 1.0 | 299 | 2.1 O | 1.6 P | 2.9 C&c |
| 170 | 1.5 | 277 | 1.1 O | 1.4 P | 1.5 C&c |
| 170 | 2 | 252 | 0.1 O | 1.3 P | 2.0 C&c |
| 170 | 3 | 233 | 0.1 O | 1.3 P | 0.5 C&c |
| 170 | 4 | 212 | 0.1 O | 0.8 P | 0.8 C&c |
| 170 | 6 | 199 | 0.0 O | 0.8 P | 0.3 C&c |
| 170 | 8 | 193 | 0.0 O | 0.8 P | 0.4 C&c |
| 180 | 0.25 | 356 | 2.6 O | 2.9 P | 5.8 C&c |
| 180 | 0.5 | 248 | 0.7 O | 1.3 P | 0.5 C&c |
| 180 | 0.75 | 235 | 0.5 O | 0.9 P | 1.5 C&c |
| 180 | 1.0 | 228 | 0.1 O | 0.8 P | 1.5 C&c |
| 190 | 0.25 | 241 | 0.7 O | 1.3 P | 2.0 C&c |
| 190 | 0.5 | 216 | 0.1 O | 0.8 P | 1.3 C&c |

*Comparative baking tests; fermentation time 4:25 hours*

## TABLE V

SUMMARY OF COMPARATIVE BAKING TESTS ON UNBLEACHED STRAIGHT-GRADE FLOUR (HEAT TREATED AT 13.90% MOISTURE)

| Treatment | | Loaf volume in cc. | | | | | Single figure estimate | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Basic procedure | Reaction to bromate | Fermentation time* | | | Basic procedure | Reaction to bromate | Fermentation time* | | |
| Temp. in ° F. | Time in hr | | | 1.75 hr | 3.0 hr | 4.25 hr | | | 1.75 hr | 3.0 hr | 4.25 hr |
| Control | | 560 | +75 | 603 | 635 | 615 | 84 | +15 | 94 | 99 | 96 |
| 130 | 2 | 572 | +33 | 615 | 605 | 606 | 91 | + 6 | 95 | 97 | 95 |
| 130 | 4 | 580 | +19 | 583 | 599 | 602 | 92 | + 4 | 92 | 96 | 95 |
| 130 | 8 | 545 | +44 | 570 | 589 | 561 | 87 | + 7 | 92 | 94 | 90 |
| 130 | 16 | 571 | +12 | 599 | 583 | 555 | 92 | + 3 | 96 | 95 | 89 |
| 130 | 24 | 561 | − 1 | 575 | 560 | 537 | 89 | + 2 | 94 | 91 | 86 |
| 135 | 2 | 562 | +41 | 621 | 603 | 610 | 90 | + 6 | 96 | 96 | 94 |
| 135 | 4 | 555 | +39 | 607 | 594 | 564 | 89 | + 3 | 95 | 92 | 89 |
| 135 | 8 | 552 | +33 | 562 | 585 | 541 | 87 | + 6 | 92 | 93 | 85 |
| 135 | 16 | 534 | + 9 | 550 | 543 | 563 | 89 | − 1 | 89 | 88 | 87 |
| 135 | 24 | 561 | −35 | 511 | 526 | 472 | 89 | − 4 | 87 | 85 | 77 |
| 140 | 1 | 564 | +69 | 592 | 633 | 595 | 89 | + 8 | 94 | 97 | 93 |
| 140 | 2 | 568 | +42 | 573 | 610 | 575 | 90 | + 3 | 92 | 93 | 91 |
| 140 | 4 | 552 | +48 | 577 | 600 | 580 | 87 | + 8 | 92 | 95 | 91 |
| 140 | 6 | 567 | +15 | 569 | 582 | 558 | 89 | + 2 | 90 | 91 | 89 |
| 140 | 8 | 563 | − 9 | 539 | 554 | 545 | 88 | − 8 | 87 | 80 | 86 |
| 140 | 16 | 525 | −33 | 524 | 492 | 497 | 85 | − 7 | 85 | 78 | 79 |
| 140 | 24 | 530 | −57 | 492 | 473 | 432 | 84 | − 9 | 77 | 75 | 68 |
| 145 | 1 | 558 | +82 | 585 | 640 | 619 | 87 | +12 | 91 | 99 | 96 |
| 145 | 2 | 559 | +46 | 585 | 605 | 571 | 88 | + 8 | 94 | 96 | 89 |
| 145 | 3 | 553 | +48 | 565 | 601 | 556 | 89 | + 5 | 93 | 94 | 87 |
| 145 | 4 | 557 | +37 | 566 | 594 | 532 | 88 | + 5 | 91 | 93 | 85 |
| 145 | 6 | 562 | +27 | 550 | 589 | 506 | 89 | + 3 | 90 | 92 | 82 |
| 145 | 8 | 537 | + 3 | 522 | 540 | 500 | 86 | + 1 | 85 | 87 | 82 |
| 145 | 10 | 537 | −37 | 505 | 500 | 452 | 83 | − 5 | 81 | 78 | 70 |
| 150 | 0.5 | 553 | +87 | 605 | 640 | 623 | 85 | +14 | 95 | 99 | 98 |
| 150 | 1 | 548 | +82 | 592 | 630 | 592 | 85 | +13 | 94 | 98 | 93 |
| 150 | 2 | 547 | +39 | 571 | 586 | 571 | 89 | + 5 | 91 | 94 | 90 |
| 150 | 3 | 579 | −19 | 574 | 560 | 535 | 92 | − 2 | 93 | 90 | 84 |
| 150 | 4 | 572 | −33 | 561 | 539 | 495 | 89 | − 4 | 89 | 85 | 78 |
| 150 | 6 | 559 | −32 | 532 | 527 | 473 | 89 | − 6 | 87 | 83 | 76 |
| 150 | 8 | 512 | −25 | 516 | 487 | 430 | 82 | − 5 | 82 | 77 | 70 |
| 150 | 10 | 517 | −74 | 488 | 443 | 416 | 82 | −12 | 74 | 70 | 65 |
| 150 | 16 | 500 | −79 | 458 | 421 | 386 | 82 | −17 | 69 | 65 | 61 |
| 155 | 0.5 | 575 | +36 | 600 | 611 | 553 | 87 | +10 | 94 | 97 | 89 |
| 155 | 1 | 565 | +28 | 585 | 593 | 599 | 89 | + 5 | 93 | 94 | 94 |
| 155 | 2 | 541 | +17 | 564 | 558 | 510 | 87 | 0 | 91 | 87 | 83 |
| 155 | 3 | 555 | −33 | 541 | 522 | 459 | 89 | − 8 | 88 | 81 | 75 |
| 155 | 4 | 527 | −40 | 510 | 487 | 422 | 85 | − 9 | 81 | 76 | 66 |
| 155 | 6 | 496 | −71 | 468 | 425 | 405 | 78 | −15 | 72 | 63 | 62 |
| 155 | 8 | 500 | −48 | 440 | 452 | 407 | 80 | − 9 | 68 | 71 | 65 |
| 155 | 10 | 441 | −89 | 380 | 352 | 346 | 69 | −15 | 58 | 54 | 54 |
| 160 | 0.25 | 548 | +52 | 592 | 600 | 582 | 84 | +10 | 94 | 94 | 92 |
| 160 | 0.5 | 533 | +78 | 568 | 611 | 549 | 84 | +13 | 88 | 97 | 88 |
| 160 | 0.75 | 533 | +18 | 554 | 551 | 510 | 85 | 0 | 89 | 85 | 82 |
| 160 | 1.0 | 515 | +26 | 562 | 541 | 497 | 83 | + 1 | 90 | 84 | 79 |
| 160 | 1.5 | 529 | −39 | 506 | 490 | 444 | 83 | − 5 | 80 | 78 | 74 |
| 160 | 2 | 521 | −35 | 498 | 486 | 421 | 83 | − 6 | 79 | 77 | 71 |
| 160 | 3 | 479 | −57 | 423 | 422 | 370 | 76 | −10 | 68 | 66 | 62 |
| 160 | 4 | 414 | −89 | 361 | 325 | 306 | 67 | −14 | 54 | 53 | 44 |
| 160 | 6 | 352 | −69 | 296 | 283 | 279 | 57 | −16 | 42 | 41 | 39 |
| 160 | 8 | 340 | −53 | 281 | 287 | 252 | 53 | −13 | 39 | 40 | 35 |
| 170 | 0.25 | 548 | +14 | 565 | 562 | 512 | 84 | + 9 | 92 | 93 | 81 |
| 170 | 0.5 | 520 | −35 | 465 | 455 | 405 | 82 | −11 | 76 | 71 | 68 |
| 170 | 0.75 | 452 | −50 | 417 | 402 | 355 | 69 | − 6 | 66 | 63 | 57 |
| 170 | 1.0 | 384 | −41 | 329 | 343 | 299 | 58 | − 4 | 48 | 54 | 42 |
| 170 | 1.5 | 358 | −66 | 310 | 292 | 277 | 58 | −15 | 45 | 43 | 35 |
| 170 | 2 | 323 | −52 | 285 | 271 | 252 | 52 | −14 | 36 | 38 | 33 |
| 170 | 3 | 279 | −39 | 245 | 240 | 233 | 42 | −13 | 29 | 29 | 26 |
| 170 | 4 | 261 | −32 | 247 | 229 | 212 | 39 | −13 | 26 | 26 | 25 |
| 170 | 6 | 229 | −19 | 226 | 210 | 199 | 32 | −10 | 23 | 22 | 22 |
| 170 | 8 | 213 | −16 | 212 | 197 | 193 | 28 | − 8 | 22 | 20 | 21 |
| 180 | 0.25 | 491 | −86 | 432 | 405 | 356 | 76 | −13 | 68 | 63 | 59 |
| 180 | 0.5 | 333 | −61 | 281 | 272 | 248 | 48 | −12 | 37 | 36 | 28 |
| 180 | 0.75 | 290 | −46 | 242 | 244 | 235 | 37 | − 7 | 28 | 30 | 29 |
| 180 | 1.0 | 271 | −66 | 213 | 205 | 228 | 34 | − 5 | 24 | 29 | 28 |
| 190 | 0.25 | 324 | −55 | 253 | 269 | 241 | 46 | − 8 | 31 | 38 | 32 |
| 190 | 0.5 | 259 | −53 | 222 | 206 | 316 | 29 | − 3 | 24 | 26 | 26 |

*Basic formula +0.001% potassium bromate used*

The sum of these four values was taken as the "single figure estimate" of baking quality, which is given in Table V, together with their corresponding loaf volume. The figures tabulated under "reaction to bromate" were calculated in each case by subtracting the loaf volume and single figure obtained by the basic procedure, from those determined for the three-hour fermentation period with bromate addition.

Alteration in the response of the flours to the addition of bromate is very striking, becoming gradually less positive as the severity of the heat treatment is increased, until finally it is strongly negative. According to views held at present this indicates on the one hand a decrease in gluten quality or on the other an over oxidation of the flour prior to the test. Probably both these factors come into play in the case of the higher treatments.

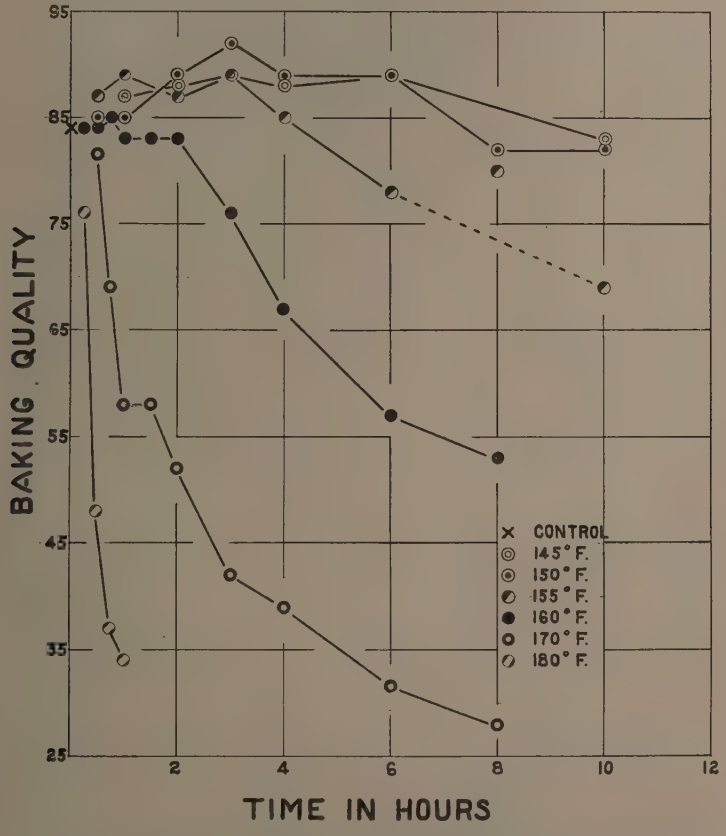



FIG. 2. *Influence of time of heating at various temperatures on the baking quality (basic procedure) of straight-grade flour (treated at 13.90% moisture).*

In Fig. 2 and 3, the baking quality (single figure estimate), as determined by the basic and bromate procedures (three-hour fermentation) is plotted as a function of the time for various temperatures used.

Fig. 2 illustrates the improvement in baking quality (determined by the basic prodecure) and confirms, in a general way, the findings of Kent-Jones (19). The results obtained, however, fail to reveal a heat treatment below which no

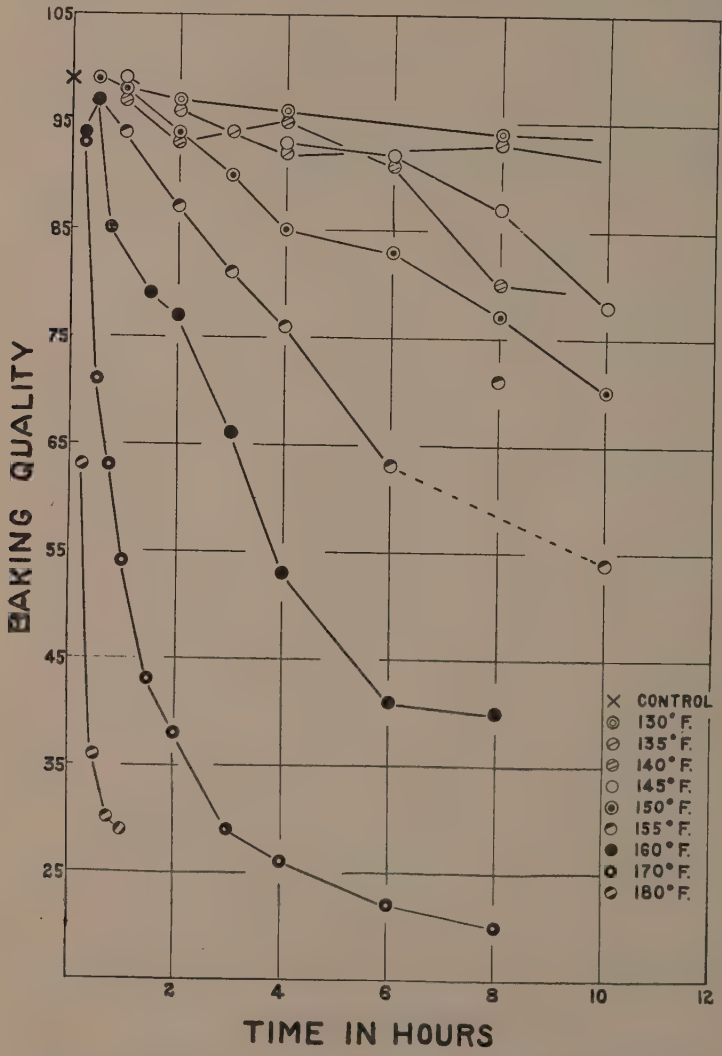



FIG. 3. *Influence of time of heating at various temperatures on the baking quality (bromate procedure) of straight-grade flour (treated at 13.90% moisture).*

alteration in baking quality takes place, nor do they show any evidence of a sharp line of demarcation where marked improvement occurs. To ascertain this point, several treatments were conducted at 120° F. (48.8° C.) and 125° F. (51.7° C.) and progressive improvement was observed with increasing times of treatment. Undoubtedly, however, there exists a temperature and time at which no alteration in baking quality will take place. The results confirm the statement of Kent-Jones that flour of normal moisture content can be heated for comparatively long times at fairly high temperatures without damage to baking quality. Heating for periods of time up to 24 hours at temperatures of 130° F., 135° F., 140° F., and for periods up to ten hours at 145° F., and 150° F. reveal no decrease in baking quality as determined by the basic procedure. As the temperature is raised a lengthening of the time of the treatment produces a marked decrease in baking quality.

The results, graphically presented in Fig. 3, however, are of a different nature and, in general, reveal damage to baking quality in all the treatments. These results indicate that the action of heat is in the same direction as the action of bromate, and suggest that the changes induced by heat may involve oxidation— the superimposing of an oxidizing agent on the already partially oxidized flour carrying the process too far. The improvement produced by heat in the baking quality of the control sample, (as determined by the basic procedure), is, however, in no wise comparable to that brought about by the addition of bromate. In this respect, the results are in agreement with the conclusions of Berliner and Ruter (2), that improvement by heat is not comparable to that afforded by the use of chemical improvers.

This fact, taken in conjunction with the decreased positive response of these flours to bromate, leads to the suggestion, as a working hypothesis, that two opposing effects are induced by heat. It might be assumed that some constituent or constituents of the flour are altered, presumably by oxidation, in such a way as to improve the baking quality, while at the same time, other constituents are changed in the reverse direction, the former effect either being induced at somewhat lower temperatures or taking place at a more rapid rate. The result would be an improvement in baking quality which, however, would be less than that brought about by the use of chemical improvers due to the unfavorable reactions produced at the same time. Hence these flours would not be expected to respond so favorably to oxidizing agents as unheated flour. When heating has been sufficient to complete the beneficial reactions, increasing increments of heat would produce a progressive degradation in baking quality.

Some support for this hypothesis seems to be provided in Fig. 4, in which baking quality (by the bromate method, three-hour fermentation) is plotted against temperature. The alteration in baking quality with increasing temperature for constant time is non-linear at the beginning (where the improving and degrading reactions are presumed to be taking place simultaneously). However, as the temperature is increased, the damage to baking quality becomes practically a linear function of the temperature for constant time.

Investigations reported by the National Research Council of Canada (24) also revealed damage to baking quality to be roughly proportional to the air temperature used in commercial drying.

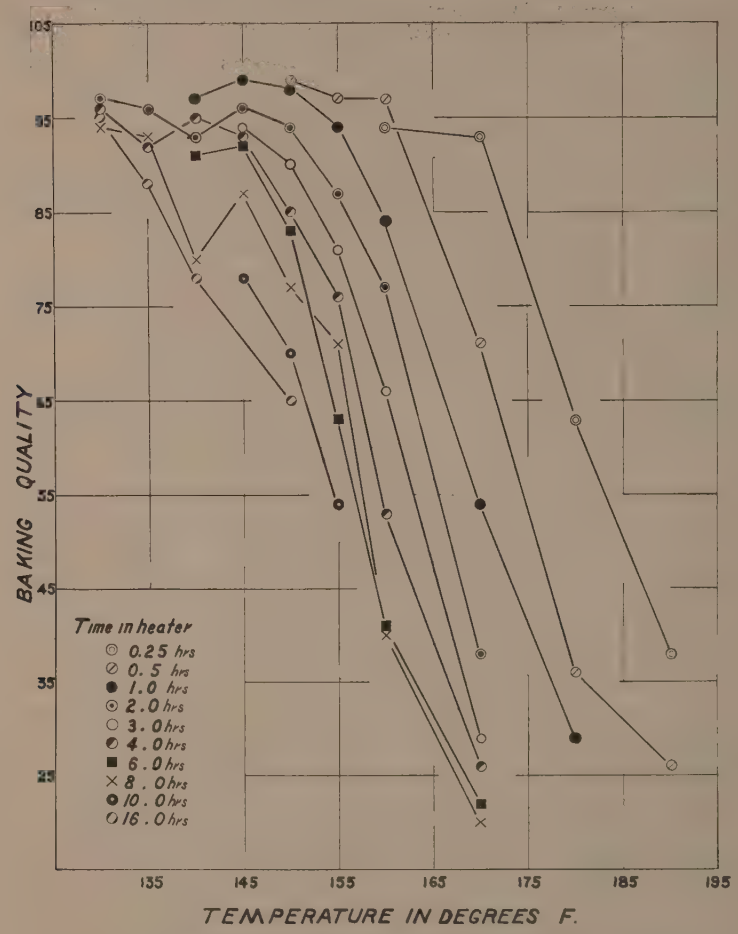



FIG. 4. *Influence of temperature of heating for various times on the baking quality (bromate method) of straight-grade flour (treated at 13.90% moisture).*

With regard to fermentation tolerance the summarized data recorded in Table V are in full disagreement with the assertions of Kent-Jones (19, 21). Perusal of the baking scores reveals that the samples, heat treated at the lower temperatures, show a greater decrease in baking quality than the control flour, as the fermentation time is extended from three (approximately the optimum for the control) to 4.25 hours. With increasing severity of treatment, signs of age and exhaustion appear at 3 and 1.75 hours respectively, the best

loaf ultimately being obtained with the latter fermentation time. Typical data illustrative of this progressive decrease in tolerance are presented graphically in Fig. 5 and 6.

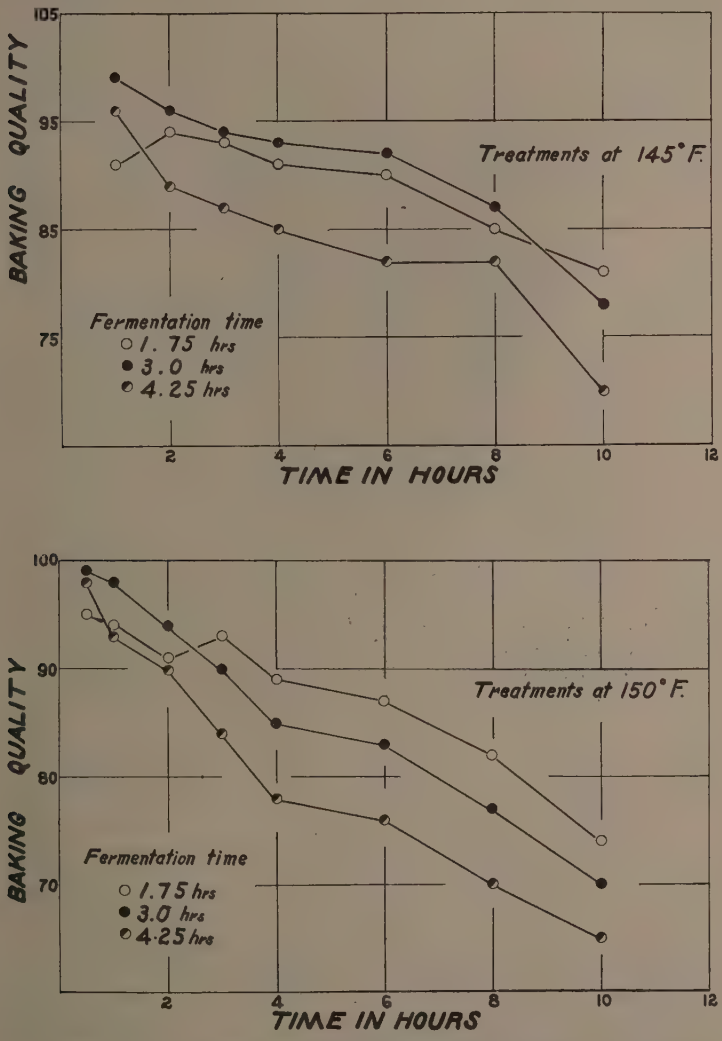



FIG. 5. *The Influence of time and temperature of heating on fermentation tolerance. (Baking quality determined by bromate procedure).*

It is difficult to conceive how the two claims,—improvement comparable to chemical improvers, and increased fermentation tolerance—can be reconciled. It is well known that such improvers as Agene, Chlorine, Novadel, Arkady

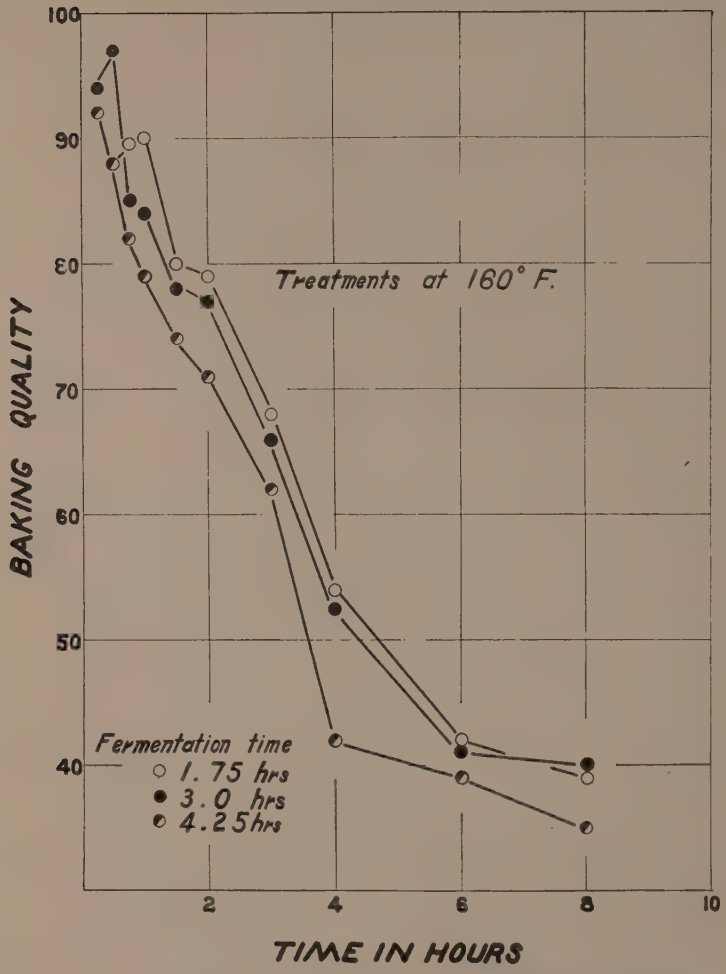



FIG. 6. *Influence of time of heating on fermentation tolerance. (Baking quality determined by bromate procedure).*

and Paniplus, aside from their bleaching properties, produce to a greater or less degree the familiar "age" symptoms, and unless suitable alterations are made in the baking formula, their use demands a decreased fermentation time. The writer's conclusions are confirmed, not only by the baking results with varying fermentation times, but also by the results of the differential test. Werner and Herman (30) have pointed out that flours non responsive to the addition of bromate, "will be found lacking, under commercial usage, in what is termed by the practical baker, strength or stability." Further, in speaking of inferior crust color these writers state: "When such detrimental crust color coincides with rough outer appearance, and ragged break, with rough or

broken "fill in", the lack of desirability of a flour of this type for bakeshop use is directly proportionate to the degree to which these symptoms become apparent."

The relation of diastatic activity to flour strength is well known and has been discussed in detail by Rumsey (25), Collatz (10), Bailey (1), and Sherwood and Bailey (28). Kent-Jones (21) considers flour strength as the ability of a flour to produce large well piled loaves, provided the gas production is sufficient. In view of the well known thermolability of enzymes in general and the tendency towards a pale crust color due to heat treatment, representative

TABLE VI

SUMMARY OF COMPARATIVE BAKING TESTS

THE INFLUENCE OF TIME AND TEMPERATURE OF HEATING ON THE BAKING QUALITY OF UNBLEACHED STRAIGHT-GRADE FLOUR (TREATED AT 13.90% MOISTURE CONTENT)*

| Treatment | | Loaf volume in cc. | General appearance | Crust color | Grain and texture |
|---|---|---|---|---|---|
| Temperature in °F. | Time in hr | | | | |
| Control** | | 672 | 4.3 O | 4.0 D | 8.0 o |
| 130 | 8 | 605 | 4.3 O | 4.1 D | 6.1 C&o |
| 135 | 8 | 604 | 4.1 O | 4.3 D | 6.3 C&o |
| 140 | 8 | 577 | 3.8 O | 4.3 D | 5.8 C&o |
| 145 | 8 | 533 | 3.0 O | 3.8 D | 4.0 C&o |
| 150 | 8 | 496 | 2.6 O | 3.8 D | 5.4 C&o |
| 155 | 8 | 428 | 2.3 O | 3.5 P | 2.8 C&o |
| 160 | 8 | 277 | 1.0 O | 1.7 P | 1.1 C&c |
| 170 | 8 | 213 | 0.0 O | 0.4 P | 0.0 C&c |
| 160 | 0.5 | 590 | 4.1 O | 4.1 D | 6.9 C&o |
| 160 | 0.75 | 536 | 4.0 O | 4.2 D | 5.0 C |
| 160 | 1.0 | 542 | 3.8 O | 4.3 D | 4.8 C |
| 160 | 1.5 | 506 | 2.5 O | 3.6 D | 3.8 C |
| 160 | 2 | 479 | 2.6 O | 3.6 D | 4.2 C&c |
| 160 | 3 | 404 | 2.1 O | 3.0 P | 2.8 C&c |
| 160 | 4 | 338 | 1.5 O | 2.0 P | 1.5 C&c |
| 160 | 6 | 306 | 1.2 O | 2.0 P | 1.5 C&c |
| 170 | 2 | 288 | 0.9 O | 1.2 P | 1.1 C&c |
| 170 | 3 | 279 | 0.5 O | 0.6 P | 0.6 C&c |
| 170 | 4 | 269 | 0.1 O | 0.6 P | 0.5 C&c |
| 170 | 6 | 247 | 0.1 O | 0.6 P | 0.3 C&c |

*Standard procedure with additions of 0.001% potassium bromate and 1.0% Fleischman's malt.
**Control = mean of five bakings

samples were baked with the addition of 1.0% Fleischman's Panamalt (a diastatic malt) and 0.001% potassium bromate to the basic formula. The baking results are recorded in Table VI. They show that the changes in baking quality, due to heat treatment, are not to be ascribed to alterations in diastatic activity. This suggests that changes in protein quality are in large part responsible for the differences observed.

## The Influence of Moisture Content on Changes in Baking Quality of Straight-Grade Flour Induced by Heat

Portions of the original straight-grade flour were exposed in shallow trays at room temperature for different times, in order to secure samples of low and varying moisture contents. A quantity of flour was dried to 4.90% moisture content by exhaustion in the vacuum oven at 35° C. A moisture of 15.11% was secured by exposing flour in a humidified cabinet for five days.

In order to study the influence of higher moistures, wheat (from which the straight-grade commercial flour was milled) was conditioned to various moisture contents. The required amount of water was sprinkled over the wheat, thoroughly mixed, and the damp wheat stored in air-tight containers for five days.

With time fixed at three hours, different heat treatments were conducted for each moisture content in an effort to secure varying degrees of damage and establish the maximum safe temperature to which wheat or flour could be heated at each moisture content. Owing to the relatively large air space above the sample in the heater, the actual moisture of the flour during treatment was undoubtedly lower than that recorded, since moisture would distil from the samples until the air in the space had become saturated with water vapor. In the case of the wheats, the heat treated samples possessed a more bleached, starchy appearance than the controls.

After treatment, a portion of each wheat sample was kept for moisture determination, the balance being weighed and spread out in boxes, provided with a jute bottom, and dried at room temperature. Samples were weighed at intervals until the weighings showed the moisture content to be between 12 and 13% and the actual moisture then determined. Four days prior to milling, the samples were conditioned to 13% moisture, and then tempered up to 15% before milling. A straight flour was milled on a two-stand Allis-Chalmers experimental mill following the flow sheet reproduced in this paper. The protein and ash content of the flours were determined, as criteria of the uniformity of milling, and these results, together with the milling yields are given in Table VII. The results show a fair degree of uniformity between the different samples.

The flours in this series were baked with and without bromate, controls being run for each moisture content. In the case of the commercially milled flour the results were so similar that only the mean for all the controls has been tabulated. With the experimentally milled flours, however, the baking quality of the control samples differed markedly. This may have been in part due to delay in the heat treatment, occasioned by trouble with the heating apparatus. The result was that several of the samples were conditioned a few days longer than desired, and incipient germination may have taken place. These facts vitiate the results on the heat treatment of wheat to some extent.

TABLE VII

MILLING DATA AND CHEMICAL ANALYSIS OF STRAIGHT-GRADE FLOUR EXPERIMENTALLY MILLED FROM WHEATS, HEAT TREATED AT VARYING MOISTURE CONTENT

| Treatment | | Milling results original basis | | | Straight-grade flour (13.5% basis) in % | Chemical analysis (dry matter basis) | |
|---|---|---|---|---|---|---|---|
| Moisture, in % | Temperature in ° F. | Total by-products in % | Total flour in % | Loss in % | | Protein in % | Ash in % |
| 15.64 | Control | 28.2 | 70.5 | 1.3 | 67.1 | 13.90 | 0.51 |
| 16.72 | " | 27.1 | 70.8 | 2.1 | 68.8 | 13.79 | 0.47 |
| 19.94 | " | 27.7 | 70.5 | 1.8 | 67.6 | 14.02 | 0.52 |
| 21.62 | " | 26.4 | 72.1 | 1.5 | 71.1 | 13.94 | 0.53 |
| 15.64 | 140 | 28.4 | 70.2 | 1.4 | 67.9 | 13.86 | 0.52 |
| 15.64 | 150 | 28.3 | 69.9 | 1.8 | 70.7 | 13.72 | 0.55 |
| 15.64 | 160 | 28.0 | 70.4 | 1.6 | 68.6 | 13.73 | 0.51 |
| 16.72 | 140 | 29.2 | 69.3 | 1.5 | 69.6 | 13.80 | 0.52 |
| 16.72 | 150 | 27.2 | 70.8 | 2.0 | 70.6 | 13.80 | 0.56 |
| 16.72 | 160 | 27.6 | 70.8 | 1.6 | 69.5 | 13.78 | 0.51 |
| 19.94 | 130 | 27.1 | 71.2 | 1.7 | 71.9 | 13.90 | 0.52 |
| 19.94 | 140 | 27.2 | 71.3 | 1.5 | 68.9 | 13.94 | 0.53 |
| 19.94 | 150 | 27.0 | 71.0 | 2.0 | 70.0 | 14.00 | 0.60 |
| 21.62 | 130 | 27.7 | 70.8 | 1.5 | 67.4 | 13.91 | 0.51 |
| 21.62 | 140 | 27.9 | 70.8 | 1.3 | 66.9 | 13.93 | 0.56 |
| 21.62 | 150 | 26.2 | 72.4 | 1.4 | 72.6 | 13.93 | .... |

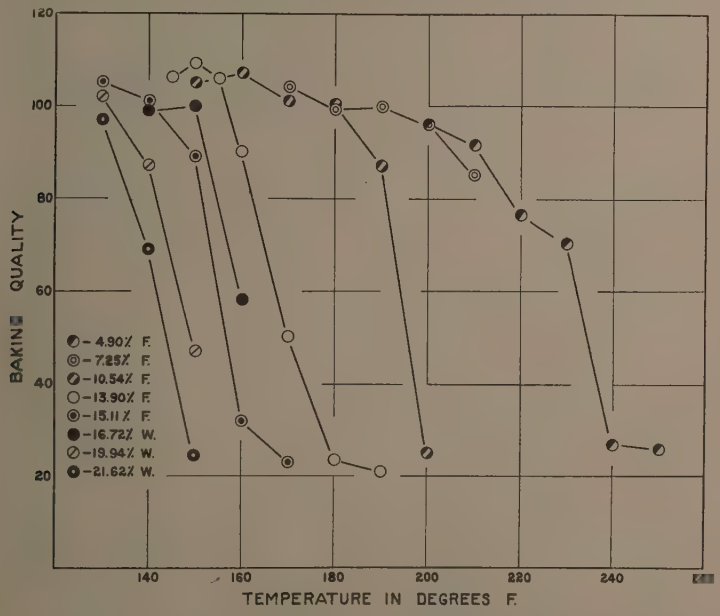



FIG. 7. *The Influence of heating wheat and flour at varying moisture contents and temperatures on baking quality (basic procedure). Time of heating is fixed at 3 hr. Baking quality is expressed as a percent of corresponding control sample. F and W indicate treatments conducted on flour and wheat respectively.*

TABLE VIII

THE EFFECT ON BAKING QUALITY PRODUCED BY VARYING THE MOISTURE CONTENT AND THE TEMPERATURE OF HEATING (TIME FIXED AT 3 HOURS)*

| Treatment | | Absorption (13.5% moisture), in % | Loaf volume, in cc. | General appearance | Crust color | Grain and texture | Single figure estimate |
|---|---|---|---|---|---|---|---|
| Moisture, in % | Temperature, in ° F. | | | | | | |
| A. HEAT TREATMENTS CONDUCTED ON FLOUR | | | | | | | |
| Flour Controls** | | 62 | 552 | 3.4 g | 5.0 | 5.7 C&c | 81 |
| 4.90 | 200 | 63 | 522 | 3.9 g | 4.3 P | 6.0 C&o | 78 |
| 4.90 | 210 | 62 | 505 | 3.2 g | 3.9 P | 5.4 C&o | 74 |
| 4.90 | 220 | 62 | 410 | 3.0 O | 3.3 P | 4.0 c | 62 |
| 4.90 | 230 | 61 | 373 | 2.0 O | 3.4 P | 4.7 c | 57 |
| 4.90 | 240 | 60 | 220 | 0.3 O | 0.0 P | 0.0 C | 22 |
| 4.90 | 250 | 60 | 210 | 0.3 O | 0.0 P | 0.0 C | 21 |
| 7.25 | 170 | 63 | 543 | 4.3 | 4.7 P | 6.9 | 84 |
| 7.25 | 180 | 64 | 519 | 4.1 | 4.5 P | 6.5 c | 80 |
| 7.25 | 190 | 64 | 502 | 4.1 | 4.7 P | 7.4 c | 81 |
| 7.25 | 200 | 64 | 489 | 3.8 | 4.5 P | 6.8 c | 78 |
| 7.25 | 210 | 64 | 444 | 2.7 O | 3.6 P | 6.0 C | 69 |
| 10.54 | 150 | 63 | 551 | 4.2 g | 4.8 P | 6.8 | 85 |
| 10.54 | 160 | 62 | 549 | 4.2 g | 4.9 P | 7.6 | 87 |
| 10.54 | 170 | 63 | 527 | 3.9 | 4.8 P | 7.0 | 82 |
| 10.54 | 180 | 64 | 523 | 3.9 | 4.8 P | 6.7 | 81 |
| 10.54 | 190 | 63 | 460 | 2.3 O | 3.8 P | 6.2 | 71 |
| 10.54 | 200 | 61 | 203 | 0.0 O | 0.0 P | 0.0 C&c | 20 |
| 13.90 | 180 | 60 | 190 | 0.0 O | 0.0 P | 0.0 C&c | 19 |
| 13.90 | 190 | 60 | 170 | 0.0 O | 0.0 P | 0.0 C&c | 17 |
| 15.11 | 130 | 63 | 521 | 3.2 O | 4.9 P | 8.4 | 85 |
| 15.11 | 140 | 62 | 515 | 3.2 O | 4.5 P | 7.7 | 82 |
| 15.11 | 150 | 63 | 437 | 2.6 O | 3.3 P | 7.5 | 72 |
| 15.11 | 160 | 61 | 237 | 0.3 O | 0.5 P | 0.5 C&c | 26 |
| 15.11 | 170 | 60 | 189 | 0.0 O | 0.0 P | 0.0 C&c | 19 |
| B. HEAT TREATMENTS CONDUCTED ON WHEAT | | | | | | | |
| 15.64 | Control | 62 | 569 | 4.1 g | 3.5 P | 8.1 | 89 |
| 16.72 | " | 61 | 597 | 4.2 g | 3.3 P | 8.4 | 92 |
| 19.94 | " | 62 | 685 | 4.2 g | 4.5 P | 8.0 | 101 |
| 21.62 | " | 62 | 680 | 4.4 g | 4.3 P | 8.3 | 102 |
| 15.64 | 140 | 62 | 592 | 4.1 g | 4.0 P | 8.4 | 92 |
| 15.64 | 150 | 62 | 580 | 4.1 g | 3.0 P | 8.3 C | 90 |
| 15.64 | 160 | 62 | 553 | 4.3 | 3.0 P | 7.8 C | 86 |
| 16.72 | 140 | 61 | 587 | 4.2 g | 3.6 P | 8.2 | 91 |
| 16.72 | 150 | 62 | 600 | 4.2 g | 3.5 P | 8.2 C | 92 |
| 16.72 | 160 | 62 | 356 | 4.3 O | 0.5 P | 5.1 | 53 |
| 19.94 | 130 | 60 | 711 | 4.4 | 4.5 P | 7.8 | 103 |
| 19.94 | 140 | 61 | 555 | 4.2 O | 2.5 P | 8.6 | 88 |
| 19.94 | 150 | 59 | 291 | 4.2 | 0.5 P | 4.5 c | 47 |
| 21.62 | 130 | 61 | 670 | 4.1 g | 3.3 P | 8.3 | 99 |
| 21.62 | 140 | 61 | 495 | 2.0 O | 1.8 P | 5.6 C | 70 |
| 21.62 | 150 | 59 | 243 | 0.0 O | 0.0 P | 0.5 C&c | 25 |

*Comparative baking tests (basic procedure)*

***Flour controls = mean of 10 bakings*

TABLE IX

THE EFFECT ON BAKING QUALITY PRODUCED BY VARYING THE MOISTURE CONTENT AND THE TEMPERATURE OF HEATING (TIME FIXED AT 3 HOURS)*

| Treatment | | Loaf volume, in cc. | General appearance | Crust color | Grain and texture | Single figure estimate |
|---|---|---|---|---|---|---|
| Moisture, in % | Temperature, in ° F. | | | | | |
| A. HEAT TREATMENTS CONDUCTED ON FLOUR | | | | | | |
| Flour Control** | | 636 | 5.0 | 5.0 | 8.2 | 98 |
| 4.90 | 200 | 562 | 4.4 O | 4.8 P | 8.1 | 90 |
| 4.90 | 210 | 519 | 3.9 O | 3.9 P | 8.4 | 85 |
| 4.90 | 220 | 452 | 3.2 O | 3.7 P | 6.7 | 72 |
| 4.90 | 230 | 388 | 2.8 O | 3.0 P | 5.8 | 62 |
| 4.90 | 240 | 269 | 0.7 O | 0.8 P | 0.5 C&c | 30 |
| 4.90 | 250 | 200 | 0.0 O | 0.3 P | 0.0 C&c | 20 |
| 7.25 | 170 | 606 | 4.7 O | 4.7 P | 9.0 | 97 |
| 7.25 | 180 | 599 | 4.5 O | 4.8 P | 8.9 | 96 |
| 7.25 | 190 | 580 | 4.8 O | 4.8 P | 8.8 | 94 |
| 7.25 | 200 | 538 | 3.9 O | 4.8 P | 8.7 | 89 |
| 7.25 | 210 | 471 | 3.3 O | 3.9 P | 8.4 | 79 |
| 10.54 | 150 | 639 | 5.0 | 4.8 P | 8.5 | 99 |
| 10.54 | 160 | 602 | 4.9 O | 4.9 P | 9.1 | 97 |
| 10.54 | 170 | 606 | 4.8 O | 4.9 P | 9.0 | 97 |
| 10.54 | 180 | 539 | 3.9 O | 4.8 P | 8.3 | 87 |
| 10.54 | 190 | 423 | 2.9 O | 3.0 P | 6.5 C | 68 |
| 10.54 | 200 | 200 | 0.0 O | 0.0 P | 0.3 C&c | 20 |
| 13.90 | 180 | 197 | 0.0 O | 0.0 P | 0.0 C&c | 20 |
| 13.90 | 190 | 178 | 0.0 O | 0.0 P | 0.0 C&c | 18 |
| 15.11 | 130 | 487 | 3.8 O | 4.5 P | 7.6 | 80 |
| 15.11 | 140 | 470 | 3.4 O | 4.0 P | 6.9 | 75 |
| 15.11 | 150 | 377 | 2.6 O | 2.5 P | 5.0 | 58 |
| 15.11 | 160 | 233 | 0.5 O | 0.3 P | 1.0 C&c | 27 |
| 15.11 | 170 | 196 | 0.0 O | 0.0 P | 0.3 C&c | 20 |
| B. HEAT TREATMENTS CONDUCTED ON WHEAT | | | | | | |
| 15.64 | Control | 651 | 4.8 | 3.1 P | 8.5 | 99 |
| 16.72 | " | 701 | 4.8 | 3.1 P | 8.5 | 103 |
| 19.94 | " | 760 | 4.7 | 5.0 | 8.1 | 110 |
| 21.62 | " | 736 | 4.4 | 4.3 P | 8.5 | 108 |
| 15.64 | 140 | 656 | 4.6 O | 3.5 P | 8.8 | 100 |
| 15.64 | 150 | 615 | 4.6 O | 3.0 P | 8.8 | 96 |
| 15.64 | 160 | 465 | 3.2 O | 2.3 P | 7.3 | 74 |
| 16.72 | 140 | 650 | 4.3 O | 3.8 P | 8.6 | 99 |
| 16.72 | 150 | 589 | 4.6 O | 3.0 P | 9.1 | 94 |
| 16.72 | 160 | 293 | 1.1 O | 0.3 P | 2.6 C&c | 38 |
| 19.94 | 130 | 730 | 4.7 | 4.0 P | 8.3 | 107 |
| 19.94 | 140 | 538 | 3.4 O | 2.4 P | 6.0 | 78 |
| 19.94 | 150 | 257 | 0.7 O | 0.3 P | 1.5 C&c | 31 |
| 21.62 | 130 | 579 | 4.2 O | 2.3 P | 8.1 | 89 |
| 21.62 | 140 | 440 | 2.3 O | 1.6 P | 5.3 | 64 |
| 21.62 | 150 | 232 | 0.2 O | 0.3 P | 1.0 C&c | 27 |

**Comparative baking tests (bromate procedure)*

***Flour control = mean of 9 bakings*

TABLE X

SUMMARY OF COMPARATIVE BAKING TESTS.
THE EFFECT ON BAKING QUALITY PRODUCED BY VARYING THE MOISTURE CONTENT AND THE TEMPERATURE OF HEATING (TIME FIXED AT 3 HOURS)

| Treatment | | Loaf volume in cc. | | Single figure estimate | | | |
|---|---|---|---|---|---|---|---|
| Moisture, in % | Temperature, in °F. | Without bromate | With 0.001% potassium bromate | Without bromate | With 0.001% $KBrO_3$ | Expressed as per cent of control | |
| | | | | | | Without $KBrO_3$ | With $KBrO_3$ |
| A. HEAT TREATMENTS CONDUCTED ON FLOUR | | | | | | | |
| Flour Controls | | 552 | 636 | 81 | 98 | | |
| 4.90 | 200 | 522 | 562 | 78 | 90 | 96 | 92 |
| 4.90 | 210 | 505 | 519 | 74 | 85 | 91 | 87 |
| 4.90 | 220 | 410 | 452 | 62 | 72 | 77 | 74 |
| 4.90 | 230 | 373 | 388 | 57 | 62 | 70 | 63 |
| 4.90 | 240 | 220 | 269 | 22 | 30 | 27 | 31 |
| 4.90 | 250 | 210 | 200 | 21 | 20 | 26 | 20 |
| 7.25 | 170 | 543 | 606 | 84 | 97 | 104 | 99 |
| 7.25 | 180 | 519 | 599 | 80 | 96 | 99 | 98 |
| 7.25 | 190 | 502 | 580 | 81 | 94 | 100 | 96 |
| 7.25 | 200 | 489 | 538 | 78 | 89 | 96 | 91 |
| 7.25 | 210 | 444 | 571 | 69 | 79 | 85 | 81 |
| 10.54 | 150 | 551 | 639 | 85 | 99 | 105 | 101 |
| 10.54 | 160 | 549 | 602 | 87 | 97 | 107 | 99 |
| 10.54 | 170 | 527 | 606 | 82 | 97 | 101 | 99 |
| 10.54 | 180 | 523 | 539 | 81 | 87 | 100 | 89 |
| 10.54 | 190 | 460 | 423 | 71 | 68 | 88 | 69 |
| 10.54 | 200 | 203 | 200 | 20 | 20 | 25 | 20 |
| 13.90 | 180 | 190 | 197 | 19 | 20 | 24 | 20 |
| 13.90 | 190 | 170 | 178 | 17 | 18 | 21 | 18 |
| 15.11 | 130 | 521 | 487 | 85 | 80 | 105 | 82 |
| 15.11 | 140 | 515 | 470 | 82 | 75 | 101 | 76 |
| 15.11 | 150 | 437 | 377 | 72 | 58 | 89 | 64 |
| 15.11 | 160 | 237 | 233 | 26 | 27 | 32 | 28 |
| 15.11 | 170 | 189 | 196 | 19 | 20 | 23 | 20 |
| B. HEAT TREATMENTS CONDUCTED ON WHEAT | | | | | | | |
| 15.64 | Control | 569 | 651 | 89 | 99 | | |
| 16.72 | " | 597 | 701 | 92 | 103 | | |
| 19.94 | " | 685 | 760 | 101 | 110 | | |
| 21.62 | " | 680 | 736 | 102 | 108 | | |
| 15.64 | 140 | 592 | 656 | 92 | 100 | 103 | 101 |
| 15.64 | 150 | 580 | 615 | 90 | 96 | 101 | 97 |
| 15.64 | 160 | 553 | 465 | 86 | 74 | 97 | 75 |
| 16.72 | 140 | 587 | 650 | 91 | 99 | 99 | 96 |
| 16.72 | 150 | 600 | 589 | 92 | 94 | 100 | 91 |
| 16.72 | 160 | 356 | 293 | 53 | 38 | 58 | 37 |
| 19.94 | 130 | 711 | 730 | 103 | 107 | 102 | 97 |
| 19.94 | 140 | 555 | 538 | 88 | 78 | 87 | 71 |
| 19.94 | 150 | 291 | 257 | 47 | 31 | 46 | 28 |
| 21.62 | 130 | 670 | 579 | 99 | 89 | 97 | 82 |
| 21.62 | 140 | 495 | 440 | 70 | 64 | 69 | 59 |
| 21.62 | 150 | 243 | 232 | 25 | 27 | 24 | 25 |

The detailed baking results are given in Tables VIII and IX, and the summarized results recorded in Table X.

The same general trend was observed in the baking quality as had been noted with increasing temperature of heating at 13.90% moisture, the heat-damaged flour yielding loaves possessing the same general characteristics. The temperature, however, at which pronounced alteration in baking quality took place was very markedly lowered by an increase in the moisture content of the material undergoing treatment. This is readily discerned in Fig. 7, in which the baking quality of each sample, as determined without bromate, is expressed as a percentage of the corresponding control. Fig. 8 was similarly constructed from the baking quality as determined with bromate. From Fig. 7, for example, it is seen that flour containing 7.25% moisture heated at 200° F. was but slightly damaged, while flour with 15.11% moisture heated at 200° F. resulted in a quality only 25% of that of the unheated flour.

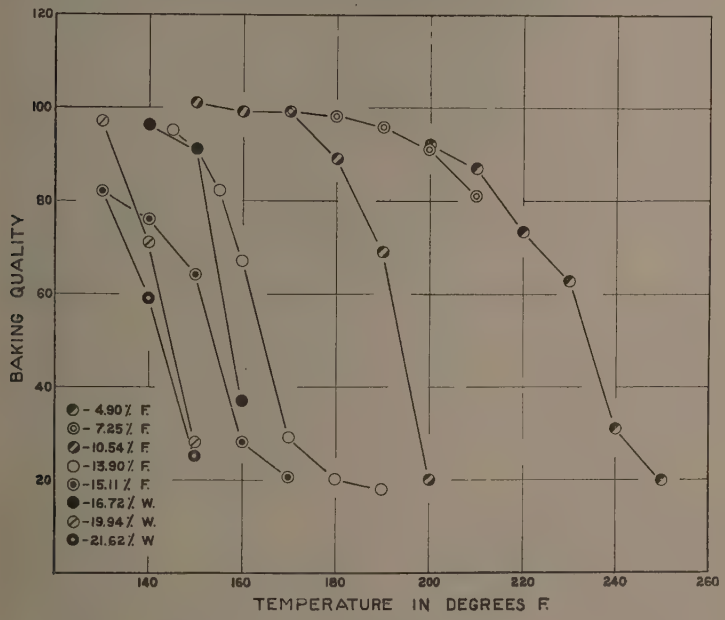



FIG. 8. *The influence of heating wheat and flour at varying moisture contents and temperatures on baking quality (bromate procedure). Time of heating is fixed at 3 hr. Baking quality is expressed as a percent of corresponding control sample. F and W indicate treatments conducted on flour and wheat respectively.*

The influence of increasing moisture content at constant temperature is apparently not linear. As the moisture is increased, no appreciable alteration in baking quality of the flour is observed, but further increases result in a very sudden and marked decrease in baking quality. This is exemplified by the photographs in Plate V.

While definite conclusions cannot be drawn from the heat treatment of the wheat, owing to the irregularities previously mentioned, the results indicate that the heat treatment of wheats at a given moisture produces less damage than the same conditions bring about with flour.

These results confirm the observations made by the Associate Committee on Grain Research (National Research Council, Canada, (24) that damage to baking quality brought about by commercial drying was associated in part with the drying of wheat carrying excessive moisture. In commercial drying, however, the influence of moisture content is partly obscured due to the increased difference between air and wheat temperature at the higher moisture levels because of the cooling effect of evaporation.

## Acknowledgments

The author wishes to thank Dr. C. H. Bailey of the University of Minnesota for his counsel and assistance; Mr. S. T. Hadley and Mr. C. B. Conway, for valuable technical assistance. His thanks are also due to Mr. A. W. Alcock, Chief Chemist, Western Canada Flour Mills Company, Limited, Winnipeg, for his kindness in supplying experimental material, and also for valuable assistance rendered in the judging of the loaves.

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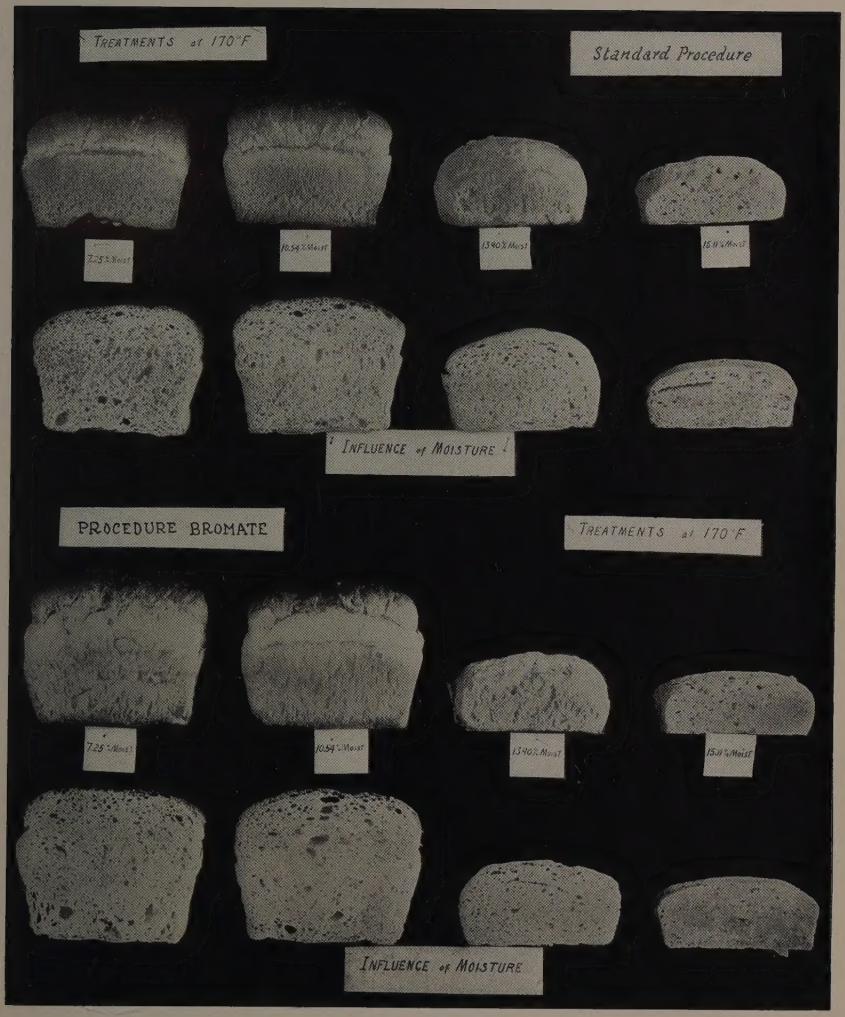


*The influence of varying moisture content (with temperature and time of heating fixed) on baking quality of straight-grade flour, as determined by the basic and bromate procedure.*

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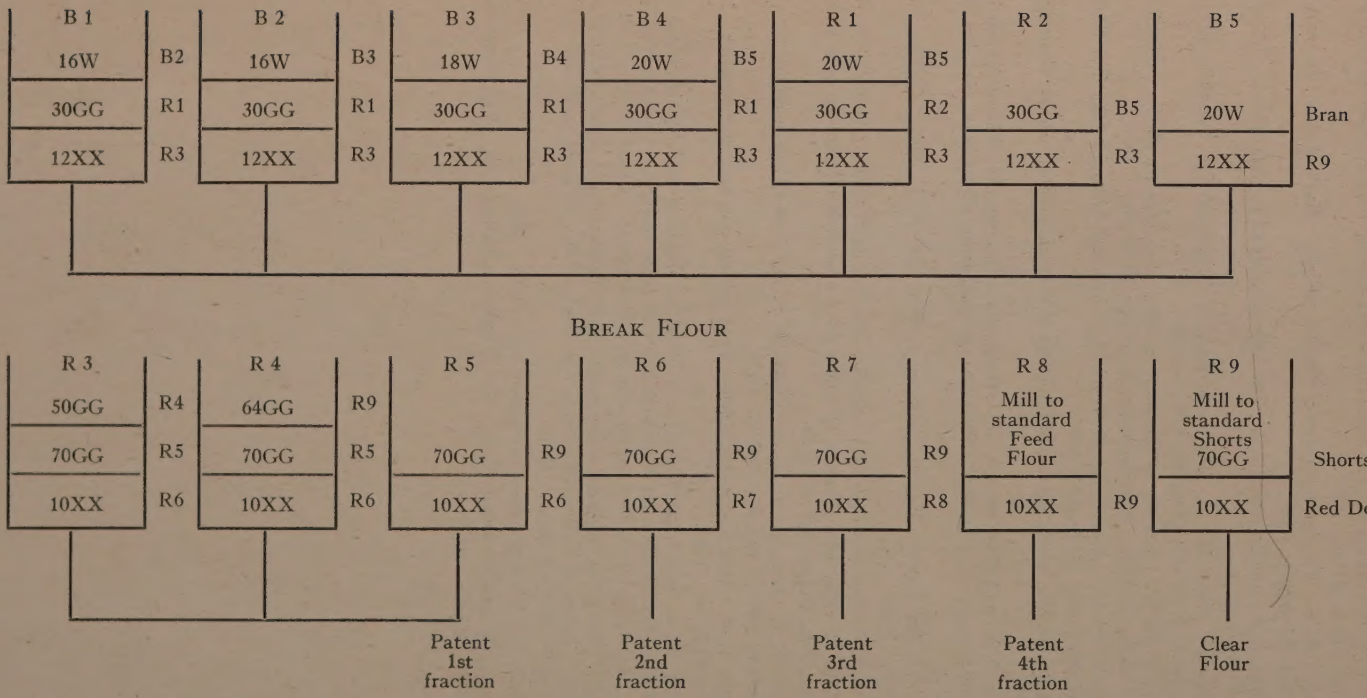
## Flow Sheet for Experimental Mill




*In milling, a "straight-grade" include all the flour milled except the Red Dog.*
*In milling 55% patent, determine weight of Break, Clear, Red Dog and total patent milled and calculate 55% of this total. Weigh out this amount, using the successive fractions of patent. Patent not required to make up the weight is added to the clear flour.*